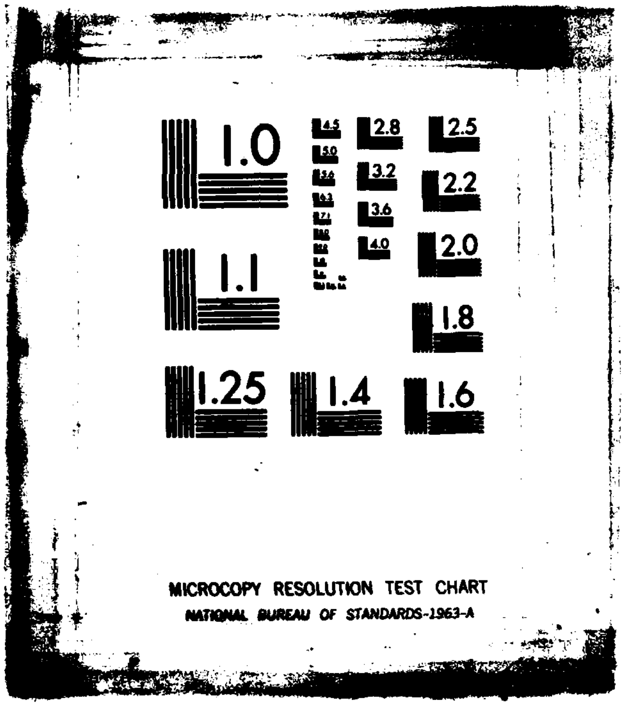
AD-A137 332   DIRECTED ENERGY TECHNOLOGY WORKING GROUP REPORT   1/2
(IDA/OSD R&M (INSTITUTE F..(U) INSTITUTE FOR DEFENSE
ANALYSES ALEXANDRIA VA SCIENCE AND TECH..   B R MAYO
UNCLASSIFIED   AUG 83 IDA-D-32 IDA/HQ-83-25898   F/G 15/3   NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Copy 10 of 200 copies

AD-E500609

AD A137332

IDA RECORD DOCUMENT D-32

DIRECTED ENERGY TECHNOLOGY WORKING GROUP REPORT

(IDA/OSD R&M STUDY)

Bruce R. Mayo
Sperry Electronic Systems
Work Group Chairman

August 1983

The views expressed within this document are those of the working group only. Publication of this document does not indicate endorsement by IDA, its staff, or its sponsoring agencies.

Prepared for
Office of the Under Secretary of Defense for Research and Engineering
and
Office of the Assistant Secretary of Defense
(Manpower, Reserve Affairs and Logistics)

INSTITUTE FOR DEFENSE ANALYSES
SCIENCE AND TECHNOLOGY DIVISION

84 01 23 033

IDA Log No. HQ 83-25898

The work reported in this document was conducted under contract MDA 903 79 C 0018 for the Department of Defense. The publication of this IDA Record Document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that agency.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A137 332	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Directed Energy Technology Working Group Report (IDA/OSD R&M Study)		5. TYPE OF REPORT & PERIOD COVERED Final July 1982 - August 1983
		6. PERFORMING ORG. REPORT NUMBER IDA Record Document D-32
7. AUTHOR(s) Bruce R. Mayo, Sperry Electronic Systems Working Group Chairman		8. CONTRACT OR GRANT NUMBER(s) MDA 903 79 C 0018
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Defense Analyses 1801 N. Beauregard Street Alexandria, VA 22311		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Task T-2-126
11. CONTROLLING OFFICE NAME AND ADDRESS Office of the Assistant Secretary of Defense (MRA&L), The Pentagon Washington, D.C. 20301		12. REPORT DATE August 1983
		13. NUMBER OF PAGES 184
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) DoD-IDA Management Office 1801 N. Beauregard Street Alexandria, VA 22311		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

None

18. SUPPLEMENTARY NOTES

N/A

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

reliability, maintainability, readiness, directed energy, weapon systems, system control, electric discharge laser, optics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document records the activities and presents the findings of the Directed Energy Technology Working Group, part of the IDA/OSD Reliability and Maintainability Study conducted during the period from July 1982 through August 1983.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

IDA RECORD DOCUMENT D-32

DIRECTED ENERGY TECHNOLOGY WORKING GROUP REPORT

(IDA/OSD R&M STUDY)

Bruce R. Mayo
Sperry Electronic Systems
Working Group Chairman

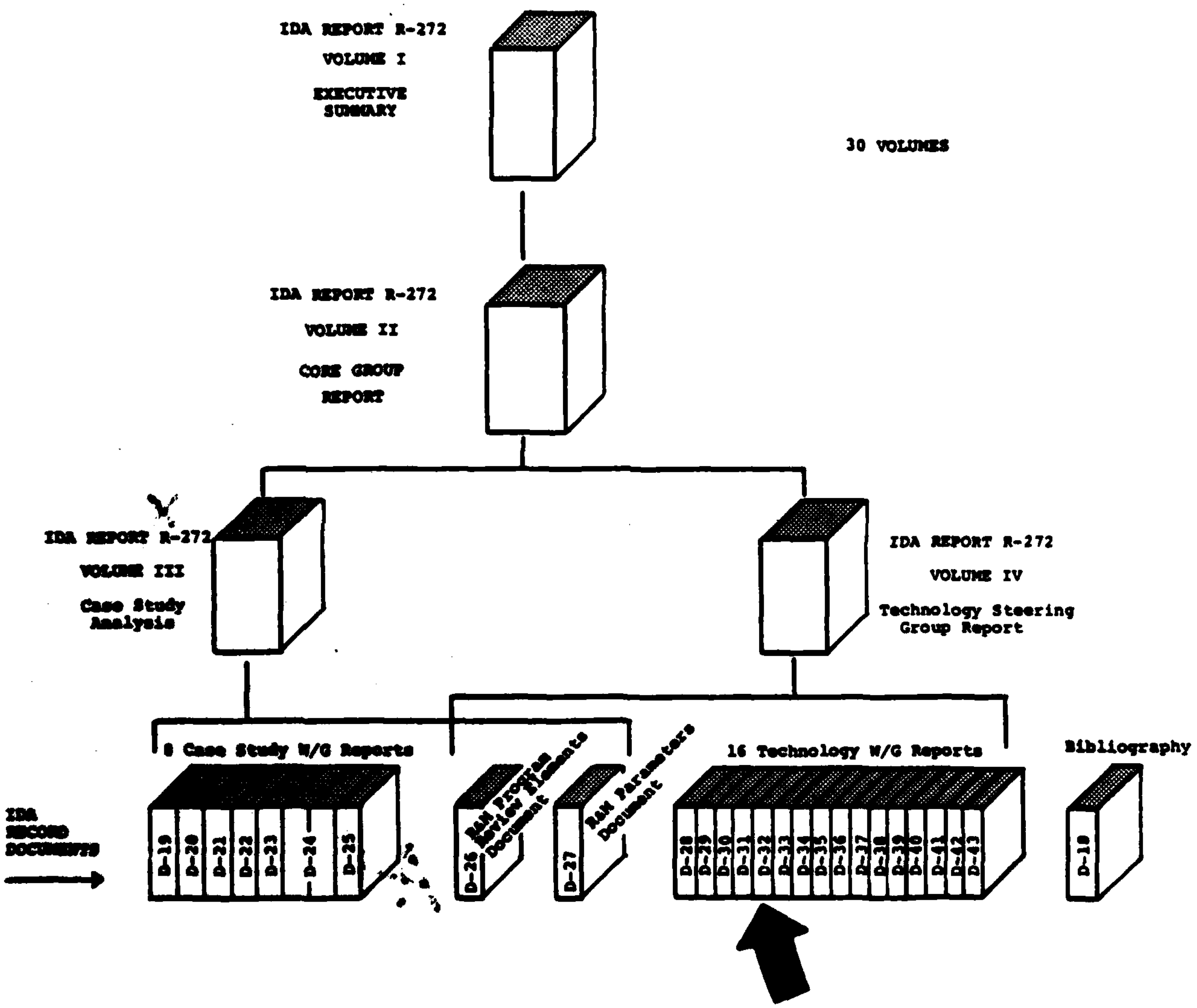
August 1983

INSTITUTE FOR DEFENSE ANALYSES
SCIENCE AND TECHNOLOGY DIVISION
1801 N. Beauregard Street, Alexandria, Virginia 22311

Contract MDA 903 79 C 0018
Task T-2-126

RELIABILITY AND MAINTAINABILITY STUDY

— REPORT STRUCTURE —



THIS DOCUMENT

(IDA Record Document D-32)

PREFACE

As a result of the 1981 Defense Science Board Summer Study on Operational Readiness, Task Order T-2-126 was generated to look at potential steps toward improving the Material Readiness Posture of DoD (Short Title: R&M Study). This task order was structured to address the improvement of R&M and readiness through innovative program structuring and applications of new and advancing technology. Volume I summarizes the total study activity. Volume II integrates analysis relative to Volume III, program structuring aspects, and Volume IV, new and advancing technology aspects.

The objective of this study as defined by the task order is:

> "Identify and provide support for high payoff actions which the DoD can take to improve the military system design, development and support process so as to provide quantum improvement in R&M and readiness through innovative uses of advancing technology and program structure."

The scope of this study as defined by the task order is:

> To (1) identify high-payoff areas where the DoD could improve current system design, development program structure and system support policies, with the objective of enhancing peacetime availability of major weapons systems and the potential to make a rapid transition to high wartime activity rates, to sustain such rates and to do so with the most economical use of scarce resources possible, (2) assess the impact of advancing technology on the recommended approaches and guidelines, and (3) evaluate the potential and recommend strategies that might result in quantum increases in R&M or readiness through innovative uses of advancing technology.

The approach taken for the study was focused on producing meaningful <u>implementable</u> recommendations substantiated by quantitative data with implementation plans and vehicles to be provided where practical. To accomplish this, emphasis was placed upon the elucidation and integration of the expert knowledge and experience of engineers, developers, managers, testers and users involved with the complete acquisition cycle of weapons systems programs as well as upon supporting analysis. A search was conducted through major industrial companies, a director was selected and the following general plan was adopted.

<u>General Study Plan</u>

Vol. III • Select, analyze and review existing successful program

Vol. IV • Analyze and review related new and advanced technology

Vol. II (• Analyze and integrate review results
(• Develop, coordinate and refine new concepts

Vol. I • Present new concepts to DoD with implementation plan and recommendations for application.

The approach to implementing the plan was based on an executive council core group for organization, analysis, integration and continuity; making extensive use of working groups, heavy military and industry involvement and participation, and coordination and refinement through joint industry/service analysis and review. Overall study organization is shown in Fig. P-1.

The basic technology study approach was to build a foundation for analysis and to analyze areas of technology to surface: technology available today which might be applied more broadly; technology which requires demonstration to finalize and reduce risk; and technology which requires action today to provide reliable and maintainable systems in the future. Program structuring implications were also considered. Tools used to accomplish

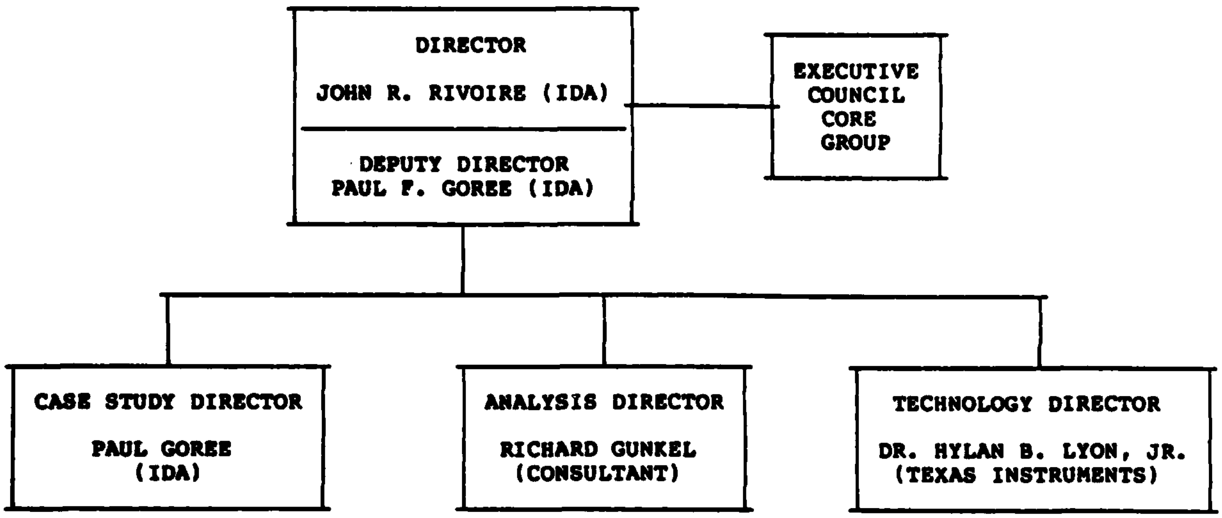


FIGURE P-1. Study Organization

this were existing documents, reports and study efforts such as the Militarily Critical Technologies List. To accomplish the technology studies, sixteen working groups were formed and the organization shown in Fig. P-2 was established.

This document records the activities and findings of the Technology Working Group for the specific technology as indicated in Fig. P-2. The views expressed within this document are those of the working group only. Publication of this document does not indicate endorsement by IDA, its staff, or its sponsoring agencies.

Without the detailed efforts, energies, patience and candidness of those intimately involved in the technologies studied, this technology study effort would not have been possible within the time and resources available.

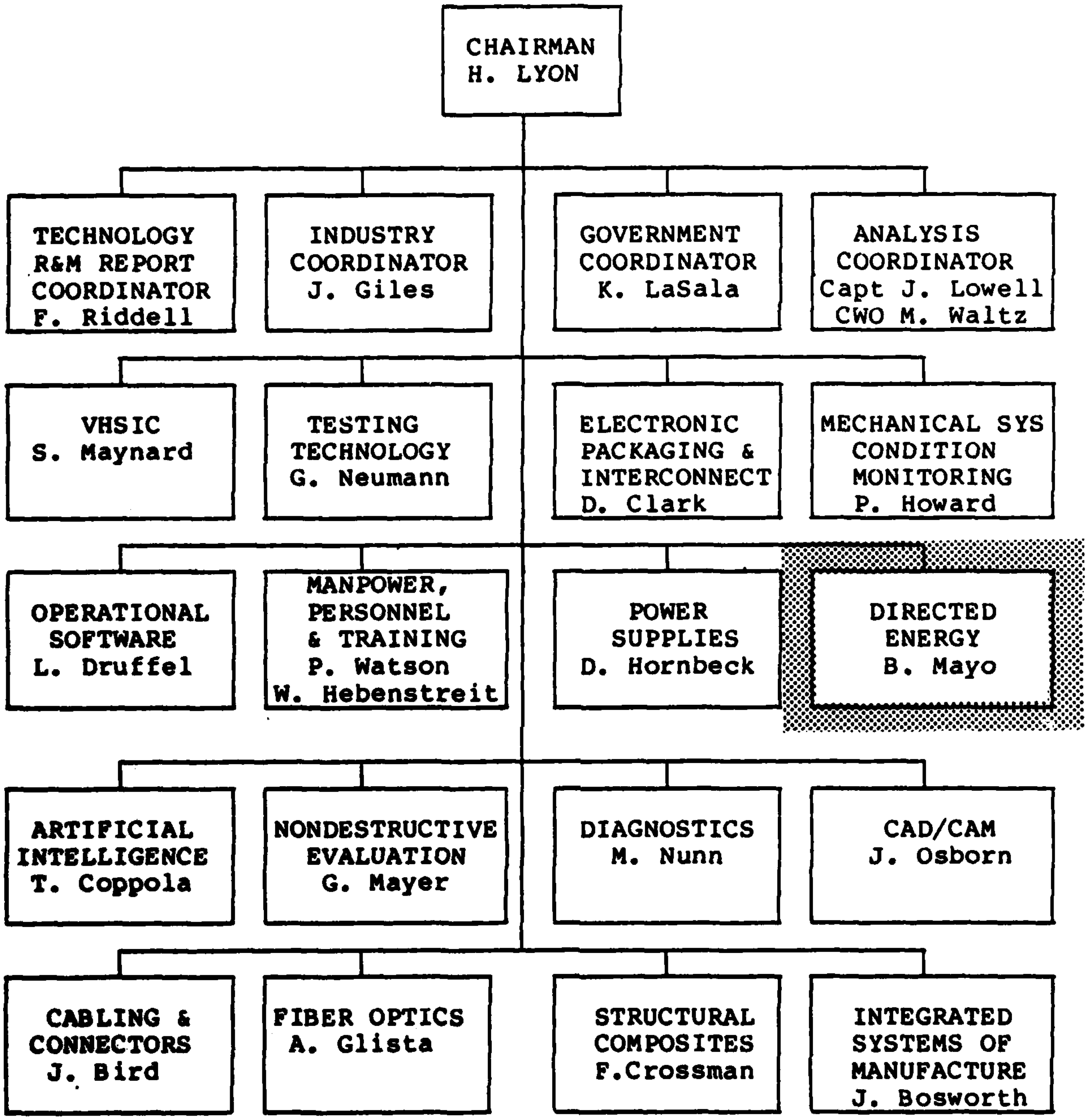
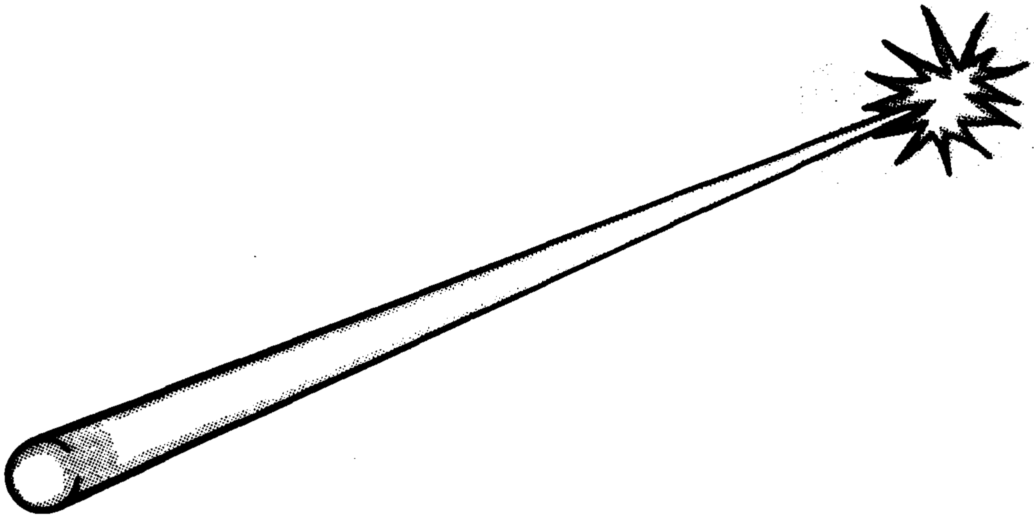


FIGURE P-2. Technology Study Organization

FINAL REPORT
DIRECTED ENERGY WORKING GROUP
(DRAFT)



Prepared for

TECHNOLOGY STEERING COMMITTEE
New Technology Working Group
Weapon Systems R&M Study Program
Department of Defense

TASK ORDER NO. MDA903-79-C0018: T-2-126

File: DEWG

1 JUNE 1983

A

FOREWORD

The case studies contained herein have been postulated for use in preparing meaniful reliability, maintainability, and availability (RMA) models in support of this study. Scenarios, missions and laser system operational requirements used in these cases are not intended to imply an existing operational capability, or that a particular application is more viable than another.

PARTICIPANTS

NAME	ORGANIZATION
MR. B.R. MAYO	SPERRY ELECTRONIC SYSTEMS
MR. J. BRACKEN	SPERRY ELECTRONIC SYSTEMS
DR. D. AHOUSE	AVCO RESEARCH CENTER
DR. G. PIPPERT	MIT/LINCOLN LABORATORIES
MR. F. STAUDT	UNITED TECHNOLOGIES RESEARCH CENTER/OATL
LT. COL. D. BOESEN	AIR FORCE WEAPONS LAB/ARL-2
MR. M. COLE	MICOM/DRSMI-RHC

CONTENTS

CONTENTS (CONT'D)

ILLUSTRATIONS

TABLE

APPENDICES

SECTION 1
INTRODUCTION

The Department of Defense (DoD) has made a long-term commitment to enhance the availability of defense weapon systems in both peace and wartime environments. As result of the Defense Science Board 1981 Summer Study an Operational Readiness, a Joint OSD-Service-Industry Study was commissioned to identify and provide support for high pay-off actions that could lead to significant improvements in future weapon systems reliability, maintainability and availability.

This study was conducted by the Institute for Defense Analysis (IDA) under the joint sponsorship of the Office of the Secretary of Defense (OASD) and the Office of the Under Secretary of Defense for Research and Engineering (OUSDRE), and work was performed under Contract MDA903-79-C-0018: T-2-126 for Manpower, Reserve Affairs and Logistics.

1.1 Purpose

The purpose of this portion of the overall R&M Study was to establish reliability and maintainability (R&M) guidelines for the acquisition of new Directed Energy Weapon Systems. In addition, new and emerging support technologies were evaluated to determine what cost effective design approaches should be considered to enhance the overall readiness and availability of new weapon systems.

1.2 Scope

The thrust of working group activity was to investigate Directed Energy Weapon Systems Technology and define what specific high pay-off actions should be taken to achieve the objectives of the study. More specifically the study addressed:

(1) What management, system-level design, fabrication and operational support considerations could lead to improved weapon system effectiveness

(2) What cost effective design considerations could reduce weapon systems development risks and improve overall design effectiveness

Specific recommendations resulting from this study were based on a current understanding of Directed Energy Weapon System Technology and a universal approach to all future weapon system designs.

1.3 Approach

The basic approach to Directed Energy Weapon System Study Group activity is illustrated in Figure 1-1. As can be seen in this figure, weapon system scenarios were selected and Directed Energy Weapon System missions and readiness conditions were defined. RMA models were then developed and key subsystem R&M goals were established based on subsystem complexity, the likelihood of equipment failure, and the general nature of the equipment and its operational environment.

Individual subsystem functions were then identified, and R&M budgets were established for each subsystem function. These allocations were then assessed relative to current state-of-art technology and trends, and functional design areas for potential R&M improvement were identified. However, since Directed Energy Weapons System technology is, for the most part, a developing technology which has provided very little operational data, R&M functional allocations and associated functional assessments are qualitive assessments at best, and they represent only an estimate of R&M performance.

Based on these subsystem R&M assessments, specific support technologies were identifed which have the potential of offering a significant R&M pay-off. Recommendations were then formulated, and they were directed to individual working groups that have been studying these technologies. A system engineering approach for acquisition management was then formulated, and a final report was generated.

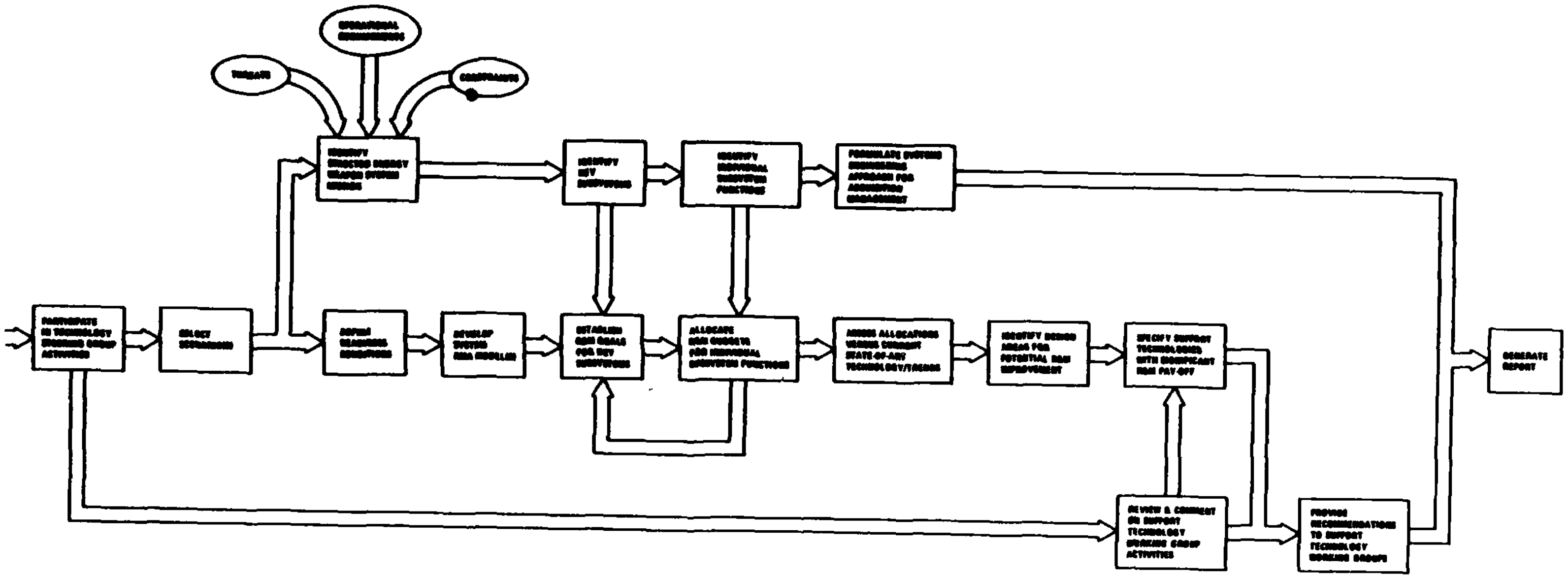


Figure 1-1: Study Approach

1.4 Issues

Several important and directly related issues exist with respect to how best to ensure a high R&M pay-off in the development of a Directed Energy Weapon System. The scaling and packaging of weapon system designs for specific application; the impact of prevailing atmospheric, meteorological and platform environmental conditions on system performance; and the potential neutralizing effects of countermeasures represent technical challenges that must be adequately addressed in order to ensure operational suitability and overall system effectiveness.

In addition, it is apparent that a high degree of redundancy will be required to ensure that acceptable levels of reliability can be achieved for space-based applications. This issue will warrant considerably more study to adequately address trade-offs associated with the practicality, suitability and technical capability of implementing complex fault tolerant and redundant designs for space.

Although each of these issues warrant considerable investigation from an RMA point of view, limited time and resources precluded the possibility of their receiving adequate attention in this study. As a result, these issues were treated as constraints, and the scope of the study was limited to potential R&M problems which dealt exclusively with the design of weapon system equipment.

1.5 Summary

The Directed Energy Working Group has attempted, in a very short time (2 months), to identify critical issues that could impact the ultimate reliability and readiness of future Directed Energy Weapon Systems. In spite of the comprehensive nature of this task, the lack of quantitative (actual) data to support analyses, and the uncertainties with respect to national priorities and commitment, a wide-range of issues were addressed. Potential weapon system applications were postulated, generic weapon system issues were identified, informed judgements were made, and specific recommendations were formulated which, for the most part, are directly applicable to any future Directed Energy Weapon System development program. In addition, guidelines for approaching the weapon system acquisition process were developed.

It should be emphasized, that this effort has only served to provide a framework for what actions must be taken to ensure the overall suitability and R&M effectiveness of future weapon system designs. Much work remains to be done, and based on a further definition of national priorities and commitments, considerations should be given to establishing an adhoc committee to monitor on-going technological developments with a view toward fulfilling the objectives of the DoD Study.

SECTION 2

SYSTEMS MANAGEMENT AND ENGINEERING

Systems management and engineering disciplines are essential to the orderly and cost-effective development of any complex weapon system, and they must be diligently applied to each phase of the system acquisition (life-cycle) process if operational objectives are to be realized.

2.1 Systems Acquisition Process

The acquisition of a Directed Energy Weapon System could result from any one or combination of the following factors:

(1) An identified deficiency in an existing mission capability

(2) A decision to establish a new capability in reponse to a technologically feasible opportunity

(3) A significant opportunity to reduce the DoD cost of ownership

(4) A response to a change in national defense policy

Any need for a Directed Energy Weapon System must be based on a comprehensive mission analysis and/or threat assessment that is clearly stated in terms of operational requirements. Alternative system concepts will be evaluated in terms of meeting these requirements, and they shall provide a basis for challenge throughout the acquisition process. The major phases of the acquisition process are shown in Figure 2-1.

2.1.1 Concept Formulation

Upon the satisfactory determination and justification of a mission need, program guidance and funding will be made available to initiate the Concept Explanation Phase. During this phase, program alternatives will be identified based on design concepts, alternative procurement strategies, expected operational capabilities, logistic

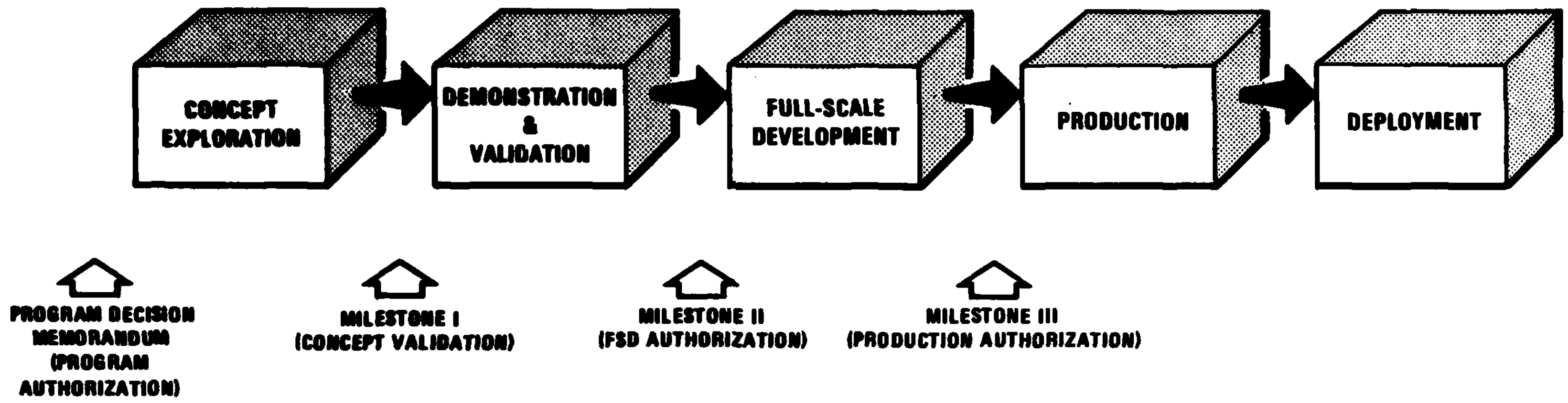


Figure 2-1: Major Systems Acquisition Process

support tails and cost. These alternates will be evaluated based on cost constraints (development cost and cost of ownership), minimum acceptable performance, and operational need dates.

Concept exploration will culminate with the preparation and submittal of a System Concept Paper (SCP), and upon validation by the DoD (MILESTONE I), thresholds and objectives for the next milestone review will be established and the Demonstration and Validation Phase will be authorized. A Test and Evaluation Master Plan (TEMP) will describe the T&E program.

2.1.2 Demonstration and Validation

During this phase of the acquistion process, a description of all system elements that most suitably satisfy the constraints imposed at MILESTONE I will be developed. The acquisition need will be reverified, and program/system alternatives will be reviewed with respect to the preferred approach.

The results of the Demonstration and Validation Phase will be documented in a Decision Coordinating Paper (DCP), where they will be described within the context of program schedule and acquisition strategy. In addition, an Integrated Program Summary (IPS), which summarized the implementation plan for the complete acquisition cycle, will be prepared, and the TEMP will be updated with emphasis being placed on the full-scale development phase. These documents will provide the basis for a DoD authorization of full-scale development (MILESTONE II).

2.1.3 Full-Scale Development

During this phase, all system elements will be designed, fabricated and integrated for test and evaluation. The purpose of this phase of the acquisition process is to confirm operational suitability and effectiveness with respect to acquisition needs.

The DCP, IPS and TEMP will be updated to reflect the results of full-scale development test and evaluation, and they shall be submitted to support a production decision at MILESTONE III. The production decision may be delegated to the sponsoring DoD military department or defense agency providing all thresholds that were established at MILESTONE II have been satisfied.

2.1.4 Production

The full-scale development system configuration will be upgraded for production during this phase. Economical rates of production will be established based on mobilization requirements and production surge capacity. Pre-planned product improvements will be evaluated as potential evolutionary alternatives to reduce technical risk control cost.

2.1.5 Deployment

Operational deployment will involve the effective utilization of the system in its intended environment. System performance will be continuously evaluated in terms of original and changing mission needs, and cost effective product improvements will be scheduled for production break-in, as appropriate.

2.2 Acquisition Management

Principles and objectives for acquisition management have been established by the DoD in support of the system acquisition process. These principles and objectives are embodied in the systems management and engineering disciplines required to deal effectively with the aspects of system procurement; system-level design; detailed design and engineering; fabrication, assembly and integration; and operational support during each phase of the system acquisition process. The relative emphasis of these considerations during each phase of the acquisition process is illustrated in Figure 2-2.

System readiness and operational suitability must be the primary objective of the acquisition process, and resources required to achieve these objectives should be commensurate to those required to achieve schedule and performance objectives. In support of these objectives, R&M requirements must be established and updated during each phase of the acquisition process. These requirements must be responsive

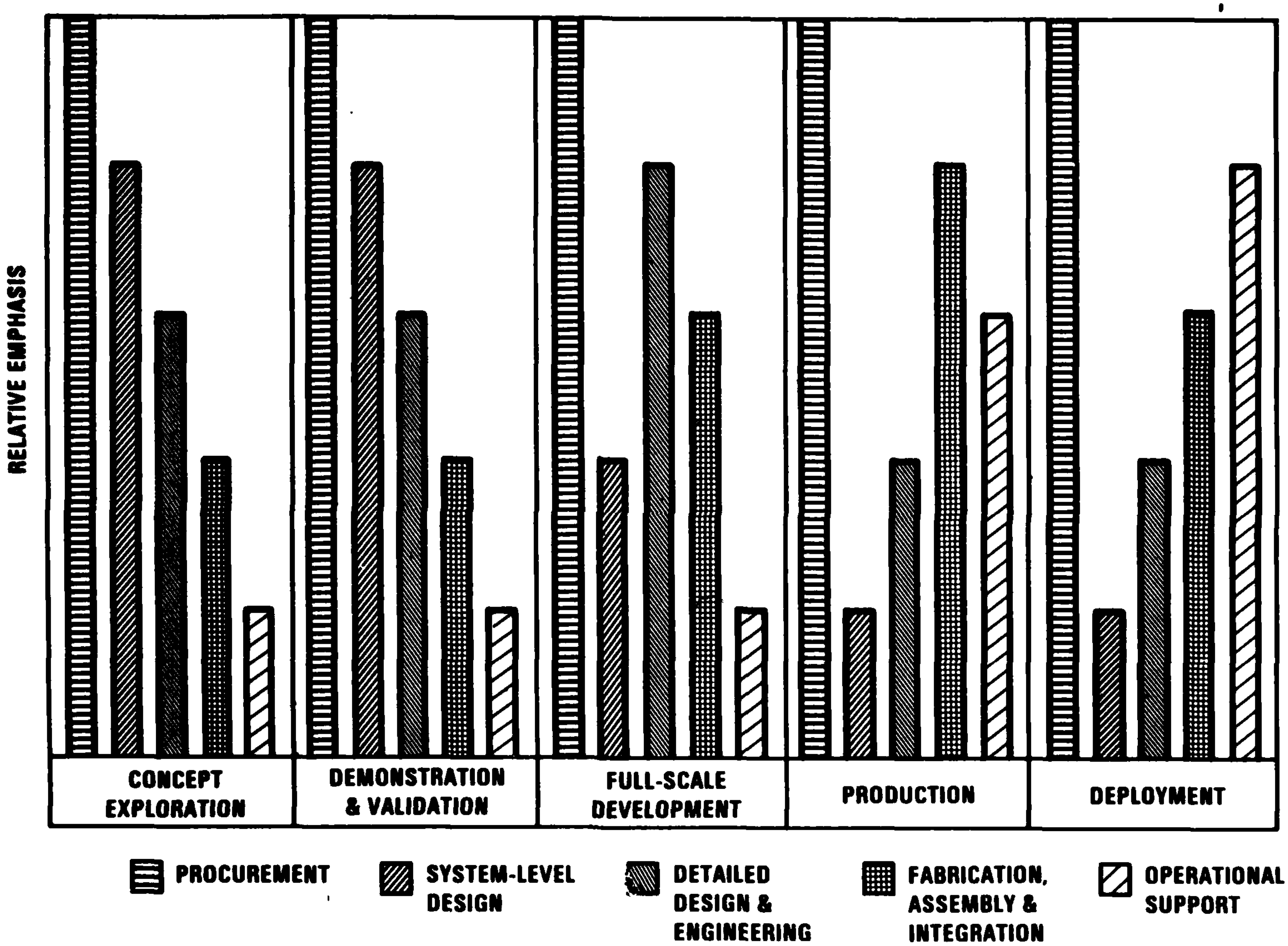


Figure 2-2: Acquisition Phase Activity

to acquisition needs, and they should be realistic in comparison to previously measured values (target system or similar systems applications).

2.3 Procurement Considerations

Specific items that should be addressed in the procurement process to assure a high degree of system readiness and overall system effectiveness include:

(1) Environmental design requirements analysis

(2) Reliability requirements analysis

(3) Failure modes, effects and criticality analysis

(4) Testability requirements and effectivness analysis

(5) Availability risk assessment and management techniques

The overall effectivness of these analytical processes can be further enhanced through the prudent application of contract incentives for performance. These incentives should be based on quantitative reliability and maintainability measure programs which can be introduced during development and production testing. Examples of such program are:

2.3.1 Environmental Stress Screening Tests

These tests are designed to detect early failures due to weak parts, workmanship defects, and other non-conformance anomalies that can be identified and removed from equipment. These tests should be conducted on parts, subassemblies and complete units, as appropriate, during both the development and production phases.

2.3.2 Reliability Development/Growth Test

These tests are pre-qualification tests that are specifically designed to enhance system reliability through the identification, analysis and correction of failures. The verification of corrective action effectiveness should be a key element of this process. These tests should not only focus on mission-critical failure modes, but they should also address frequent failure modes regardless of their mission criticality.

2.3.3 Reliability Qualification Tests

Reliability Qualification Tests should be conducted on full-scale development equipment that is representative of the approved production configuration. The purpose of these tests are to demonstrate that specified reliability requirements have been achieved.

2.3.4 Maintainability/Testability Qualification Tests

The purpose of these tests is to demonstrate that maintainability/testability requirements have been achieved. These tests shall be conducted using full-scale development equipment, tools, support equipment, documentation and software that is representative of what is to be used in the operational environment.

2.3.5 Production Reliability Acceptance Tests

The purpose of these tests is to assure that reliability has not been degraded as a result of changes in tooling, processes, work flow, design, parts qualification or other characteristics that may be unique to the production process.

2.4 System-Level Design Considerations

System level design involves the application of analysis, synthesis, evaluation and selection disciplines to establish requirements for the detailed design and engineering of system elements. The system-level design process is shown in Figure 2-3.

2.4.1 Requirements Analysis

Acquisition requirements and objectives should be reviewed with respect to organization, doctrine, tactics, threats, environment and constraints. A mission profile should then be developed which reflects acquisition needs, and these needs should be analyzed with respect to technical rationale and criteria, and economic constraints and thresholds, to develop a system model.

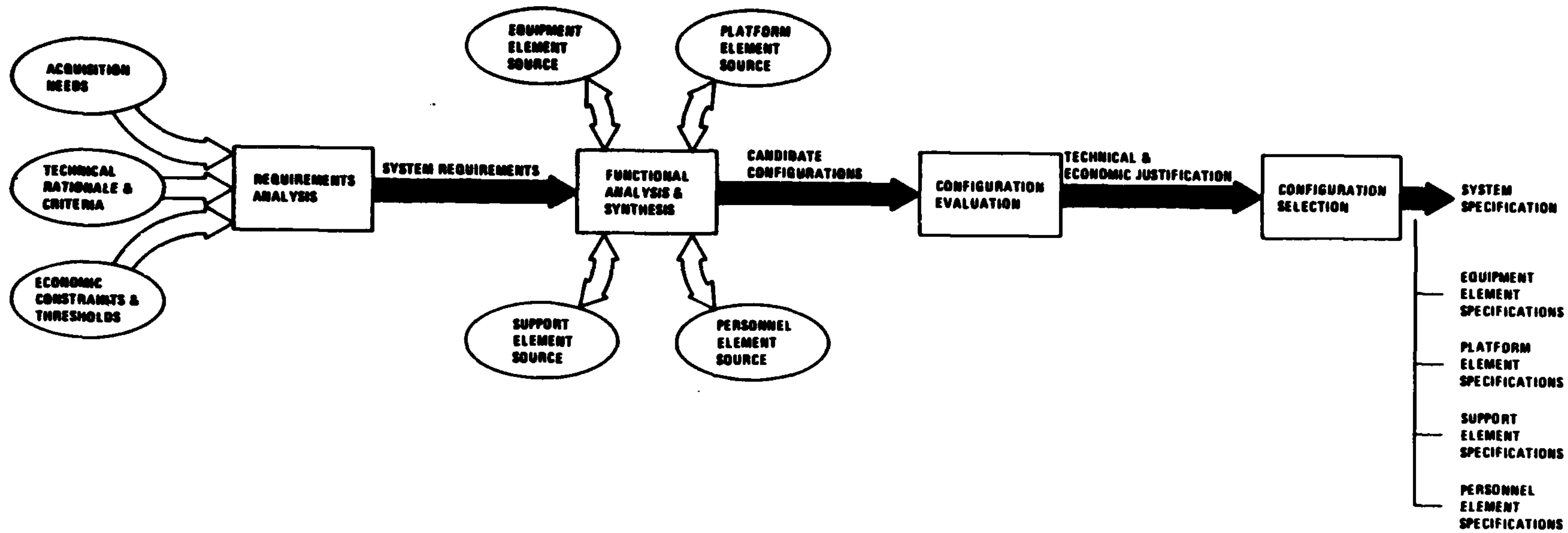


Figure 2-3: System-Level Design Process

The system model shall identify functional elements which relate to performance, operation, test, maintenance and support. Detailed functional descriptions shall be prepared for each functional element, and a "REQUIREMENTS ALLOCATION" shall be assigned based on acquisition needs. Technical Performance Parameters (TPP's) shall then be identified for each functional element, and the functional allocation process shall be extended to individual TPP's.

Requirements analysis should culminate with the preparation of a Preliminary System Specification which is supported by the system model. The requirements analysis process is shown in Figure 2-4.

2.4.2 Functional Analysis and Synthesis

A detailed functional analysis shall be performed based on information in the Preliminary System Specification. Particular attention must be given to functional interdependencies in order to avoid potential problems with functional priorities.

Hardware concepts are then formulated to address functional requirements, and these concepts are synthesized with careful consideration of design constraints, known issues and technical uncertainties. Concepts are then analyzed with respect to performance allocations, and when appropriate, adjustments will be made to allocations consistent with overall acquistion needs. Unacceptable concepts will be discarded.

By means of this process, specific candidate configurations are developed for evaluation. These configurations shall be documented in the form of schematic diagrams which identify equipment functions and interfaces. In addition, trade-off matrices shall be prepared which outline the attributes and shortcomings of each configuration, and they provide an indication of major trade-off considerations as they relate to performance (including reliability and availability), safety, design flexibility, logistics supports, schedule, cost and risk.

The functional analysis and synthesis methodology is shown in Figure 2-5.

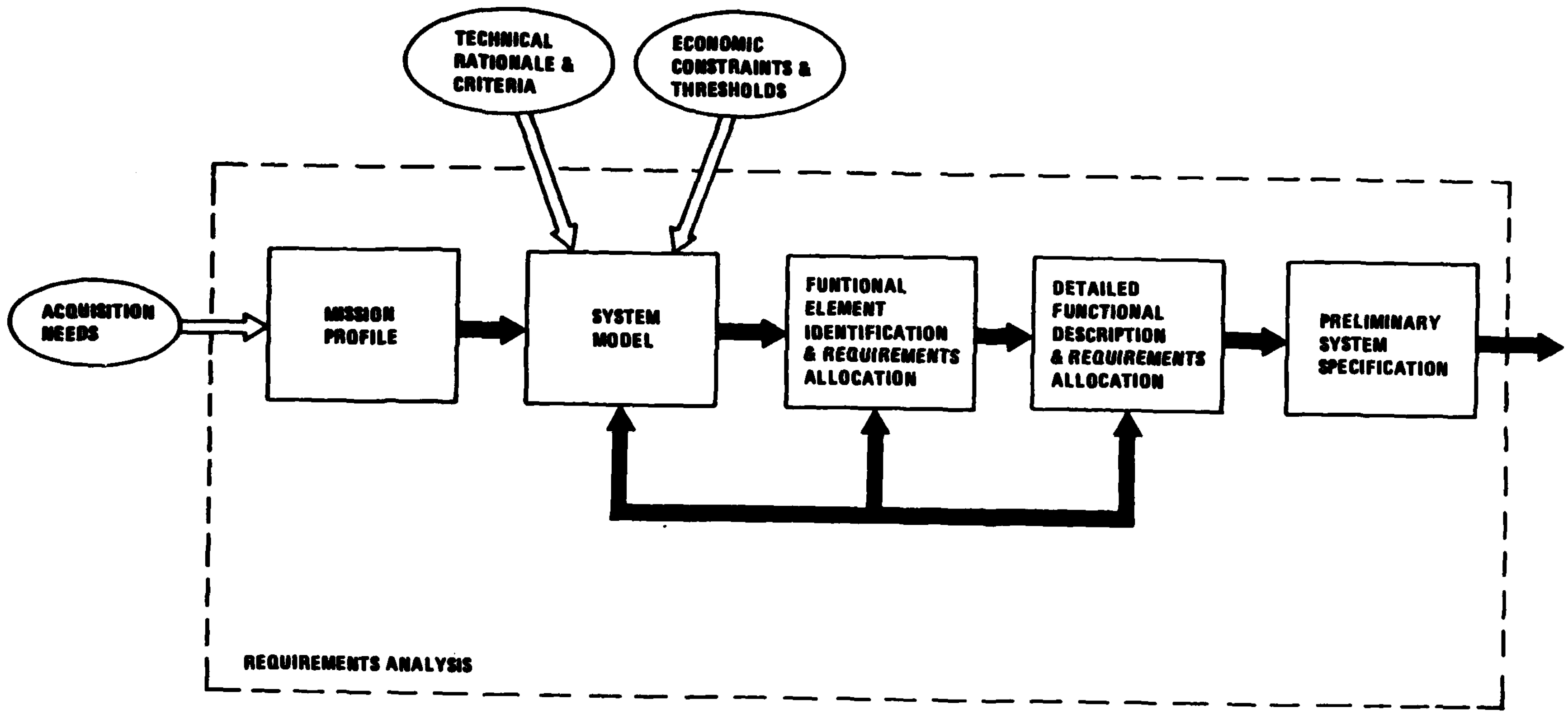


Figure 2-4: Requirements Analysis Process

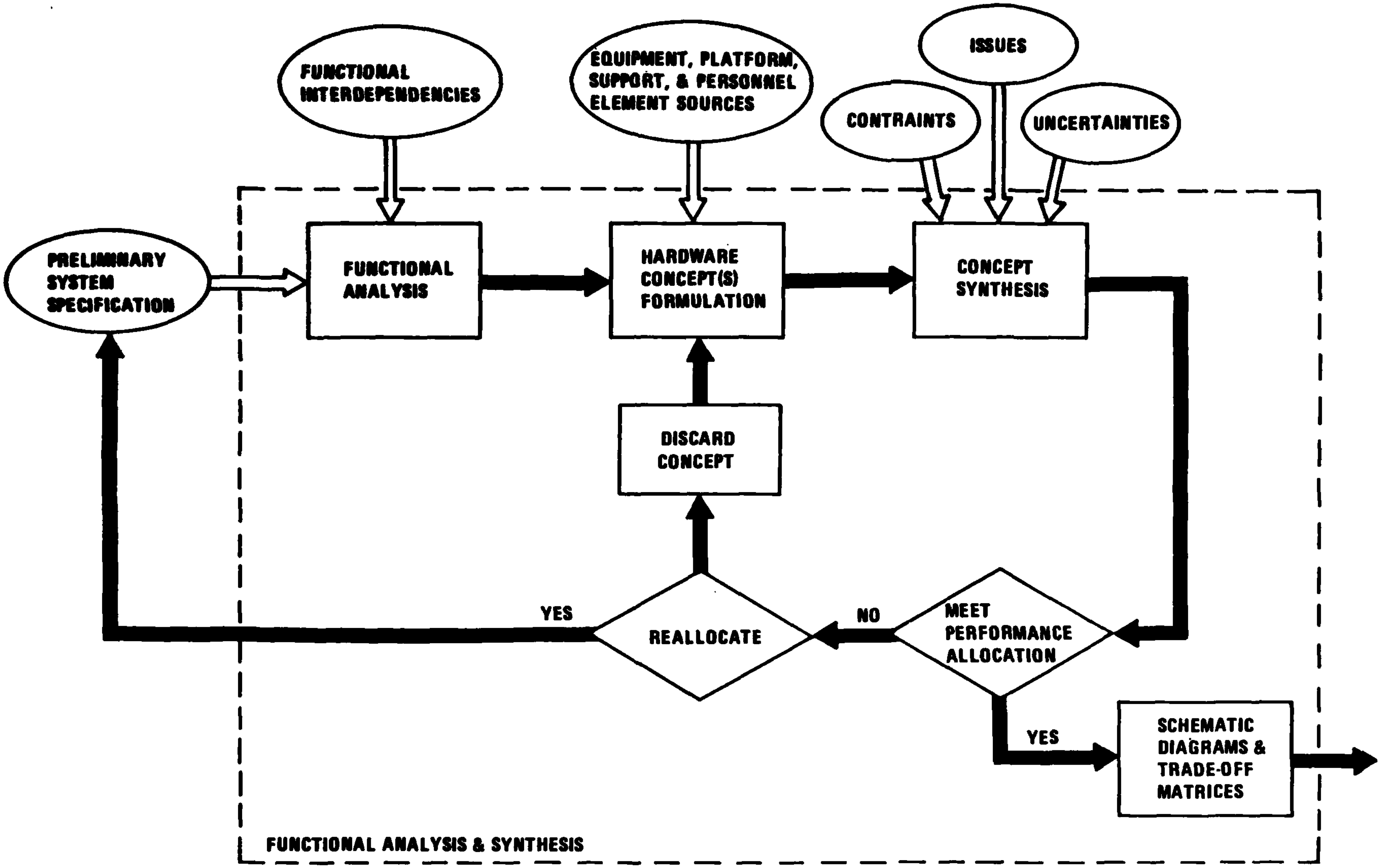


Figure 2-5: Functional Analysis and Synthesis Process

2.4.3 Configuration Evaluation

Criteria shall be established for the evaluation of candidate system configurations. These criteria shall be directly related to system acquisition needs, and they shall provide a common basis for evaluation.

Detailed trade-offs shall be conducted based on a quantitative assessment of trade-off considerations, and a Technical Figures-of-Merit (FOM) and cost estimate shall be developed for each candidate configuration.

The Configuration Evaluation Process is shown in Figure 2-6.

2.4.4 Configuration Selection

A configuration selection shall be based on overall technical FOM and cost. The preferred system configuration is the candidate configuration with the lowest cost that meets the minimum acceptable acquisition needs. Alternatively, if a maximum allowable cost is specified, the preferred system configuration is the candidate configuration with the highest FOM which does not exceed the cost limit.

Upon completion of the configuration selection process, the System Specification shall be finalized and equipment, platform, support and personnel element specifications shall be prepared which reflect system-level design-to requirements.

In addition to the generation of design-to requirements for Detailed Design and Engineering, Configuration Management and Product Assurance Plans will be implemented, a Preliminary Hazards Analysis (PHA) shall be performed, and a Technical Performance Measurement Program shall be established.

2.4.4.1 Configuration Management Plan

The Configuration Management Plan shall apply technical and administrative discipline to identify and document configuration items, control changes, provide records for configuration status accounting, and establish provisions for period configuration audits.

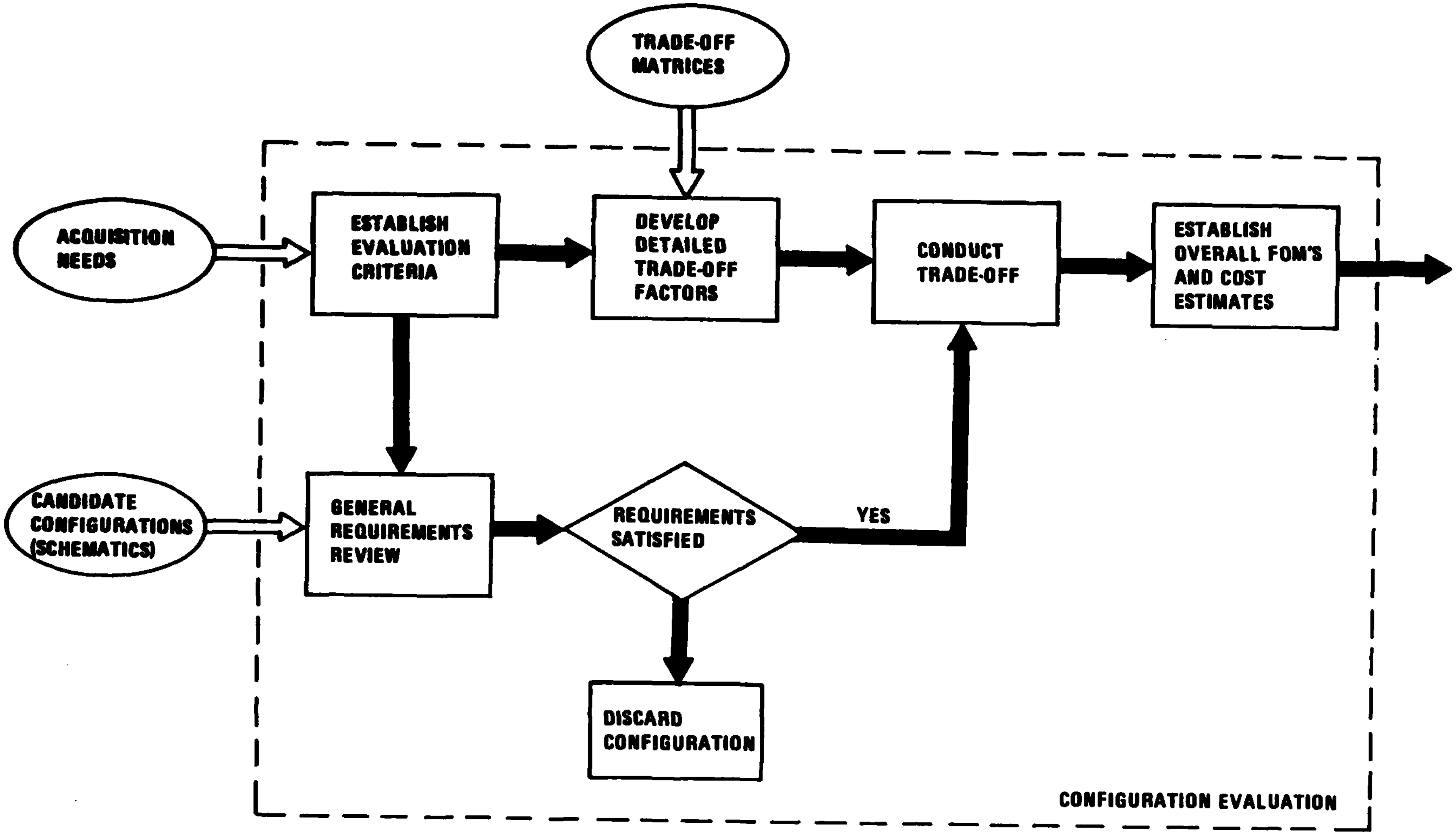


Figure 2-6: Configuration Evaluation Process

2.4.4.2 Product Assurance Plan

This plan shall invoke technical and management disciplines which will have a positive effect on system and subsystem availability, performance, and effectiveness. Specifically, this plan will include procedures and techniques for defining, measuring and improving reliability, quality, maintainability, human factors and standardization during design, fabrication and operational phases.

2.4.4.3 Preliminary Hazards Analysis (PHA)

A PHA shall be performed to obtain an initial risk assessment of the system configuration. The purpose of this analysis is to identify critical safety areas, evaluate potential hazards, and specify safety design criteria.

2.4.4.4 Technical Performance Measurement (TPM) Program

Selected Technical Performance Parameters (TPP's) which constitude a part of the system model (Reference Paragraph 2.4.1) shall be identified for technical performance measurement. These parameters shall be periodically "measured" through the life of the system, and they will provide a "PROJECTION" of system performance capability for comparison with the "REQUIREMENTS ALLOCATION." These "measurements" may be derived using analytical models, breadboard evaluation techniques, test data or operational performance data, and it is expected that the uncertainties associated with these "PROJECTIONS" will diminish as the system design matures.

The TPM Program should provide the basis for identifying residual design errors, evaluating overall system effectiveness, and introducing timely and cost effective solutions to correct system deficiencies.

2.5 Detailed Design and Engineering Considerations

Fabrication specifications and detailed drawings shall be prepared for major subsystem designs. The Product Assurance Program Plan shall be invoked, and subsystem test, maintenance, repair and training program plans shall be developed.

Subsystem Hazards Analyzes (SSHA's), and Failure Mode Effects and Criticality Analyses (FMECA) shall be conducted, and a Preliminary Spare Parts List shall be generated.

2.5.1 Subsystem Hazards Analyses (SSHA's)

The SSHA is an expansion of the SHA in a particular subsystem area. This analysis shall be performed to determine the safety aspects of subsystem functional relationships. It shall identify all equipments and components whose performance degradation or functional failure could result in a hazardous condition.

2.5.2 Failure Mode Effects and Criticality Analyses (FMECA)

The FMECA shall provide a top-down evaluation of potential system and subsystem failures at each level of indenture (system, subsystem, equipment, assembly, etc.). Each potential failure shall be analyzed to determine the failure mode, the failure indication, and the effect on overall subsystem performance.

Functional hardware interdependency block diagrams shall also be used to identify critical components with a high probability of single point failure (Safety critical failures should be incorporated in the SSHA). Design changes or other corrective actions shall be recommended for these failures, as appropriate.

2.5.3 Preliminary Spare Parts List

Preliminary Spare Parts Lists shall be prepared for each subsystem element. These lists shall be integrated at the system level to eliminate unwarranted duplication between subsystems.

2.6 Fabrication, Assembly, and Integration Considerations

During this phase of activity, individual subsystem equipment procurement specifications will be prepared, and equipment will be fabricated, assembled and integrated for source inspection, test and acceptance. A Packaging, Handling, Storage and Transportation (PHST) Plan will be prepared to move subsystems/equipments for system integration and performance testing.

During this period, the Product Assurance Plan will continue to be enforced, a Provisioning Plan and associated documentation will be prepared, an Operating and Support Hazard Analysis (O&SHA) will be conducted, and safety operating procedures and checklists shall be prepared.

2.6.1 Provisioning Plan

This plan will document the process for updating Spare Parts and Critical Components Lists and establishing the essentiality of each item based on known or projected maintenance actions and reliability predictions.

A model shall be developed to conduct sensitivity analysis and define provisioning requirements based on such criteria as spare parts list recommendations, replacement rate, long-lead time, essentiality codes and cost.

2.6.2 Operating and Support Hazard Analyses (O&SHA)

An O&SHA shall be conducted to identify potential safety hazards and determine requirements for assuring personnel and equipment safety This analysis shall address all phases of system operation, including installation, maintenance, checkout, mission conduct and shutdown. It shall also address all system operating modes during each of these phases.

More specifically, the O&SHA shall identify:

(1) Hazardous operations and tasks

(2) Hazardous conditions related to operations and tasks

(3) Causes of hazardous conditions

(4) Risks associated with hazardous conditions

(5) Preventive measures to eliminate/reduce risks

2.6.3 Safety Operating Procedures and Checklists

Safety operating procedures and checklists shall be developed from the O&SHA. The procedures and checklists shall be appropriately referenced in system operation, test and maintenance documentation.

2.7 Operational Support Considerations

An Integrated Logistics Support Plan shall be developed which addresses maintenance, repair, provisioning, and training requirements.

In addition, the Product Assurance and Technical Performance Measurement (TPM) Programs shall continue to be enforced, and a Trouble Failure and Corrective Action Program shall be implemented.

2.7.1 Integrated Logistics Support (ILS) Plan

An ILS Plan shall be developed that defines, optimizes and integrates all logistics support requirements for the system. Logistics support elements shall include planned maintenance, personnel and training, technical logistics data, support equipment, spares and repair parts, facilities and other resources as may be deemed necessary to operate and maintain the system.

Initial planning for ILS must be an integral part of the system engineering and design process so that subsequent changes and modifications to production hardware are minimized, and support requirements are based on a systematic analysis of design considerations.

2.7.2 Trouble/Failure and Corrective Action Program

The purpose of this program is to document operational failure data and associated corrective actions for failure and trend analysis. All hardware, computer software and documentation deficiencies shall be covered by this program.

Analysis results compiled from data collected at operational activities shall provide the basis for:

(1) Substantiating equipment design changes and revisions to operational procedures

(2) Verification of reliability and maintainability predictions

(3) Verification of the range and depth of spare and repair parts required to support system operation

(4) Assessment of maintenance, support and safety documentation adequacy

(5) Elimination of deficiencies in manufacturing processes and quality control procedures

SECTION 3

GENERIC WEAPON SYSTEM DESCRIPTION

A number of directed energy weapon applications (tactical and strategic) are presently being investigated by the DoD using devices with various wavelengths and power levels. For the purpose of this study, however, a generic weapon system configuration was used with emphasis being placed on high energy laser device technology. The key elements of this system configuration are shown in Figure 3-1.

The inherent technology associated with Directed Energy Weapon Systems in shown in Figure 3-2. This technology can be placed in one of three categories:

(1) Conventional (mature) technology

(2) Conventional technology that is being stressed

(3) New and esoteric state-of-art technology

Based on the present state of this technology, the risks associated with achieving RMA goals for specific applications could be considerable. It is within this context, therefore, that the use of <u>new</u> high pay-off support technologies for R&M improvement must be carefully evaluated to ensure that premature implementation is avoided and additional risk is not incurred.

3.1 <u>Weapon System Control</u>

The Weapon System Control Function shall provide for the real-time management and safe operation of the weapon system during normal and off-nominal conditions. Major functions to be performed by the Weapon Control System are resource management, system sequencing, and safety and surveillance functions. These functional relationships are shown in Figure 3-3.

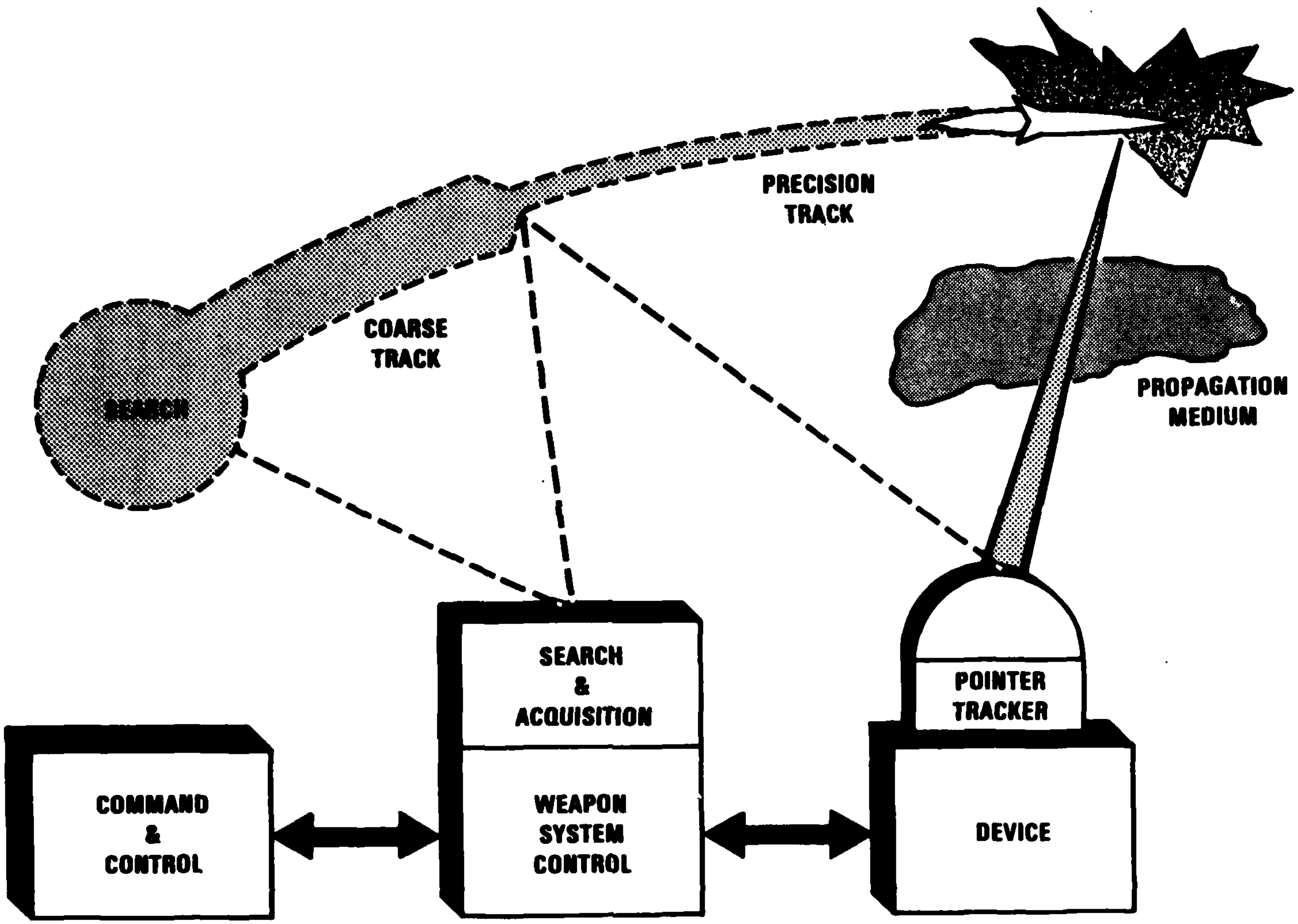


Figure 3-1: Directed Energy Weapon System Key Elements

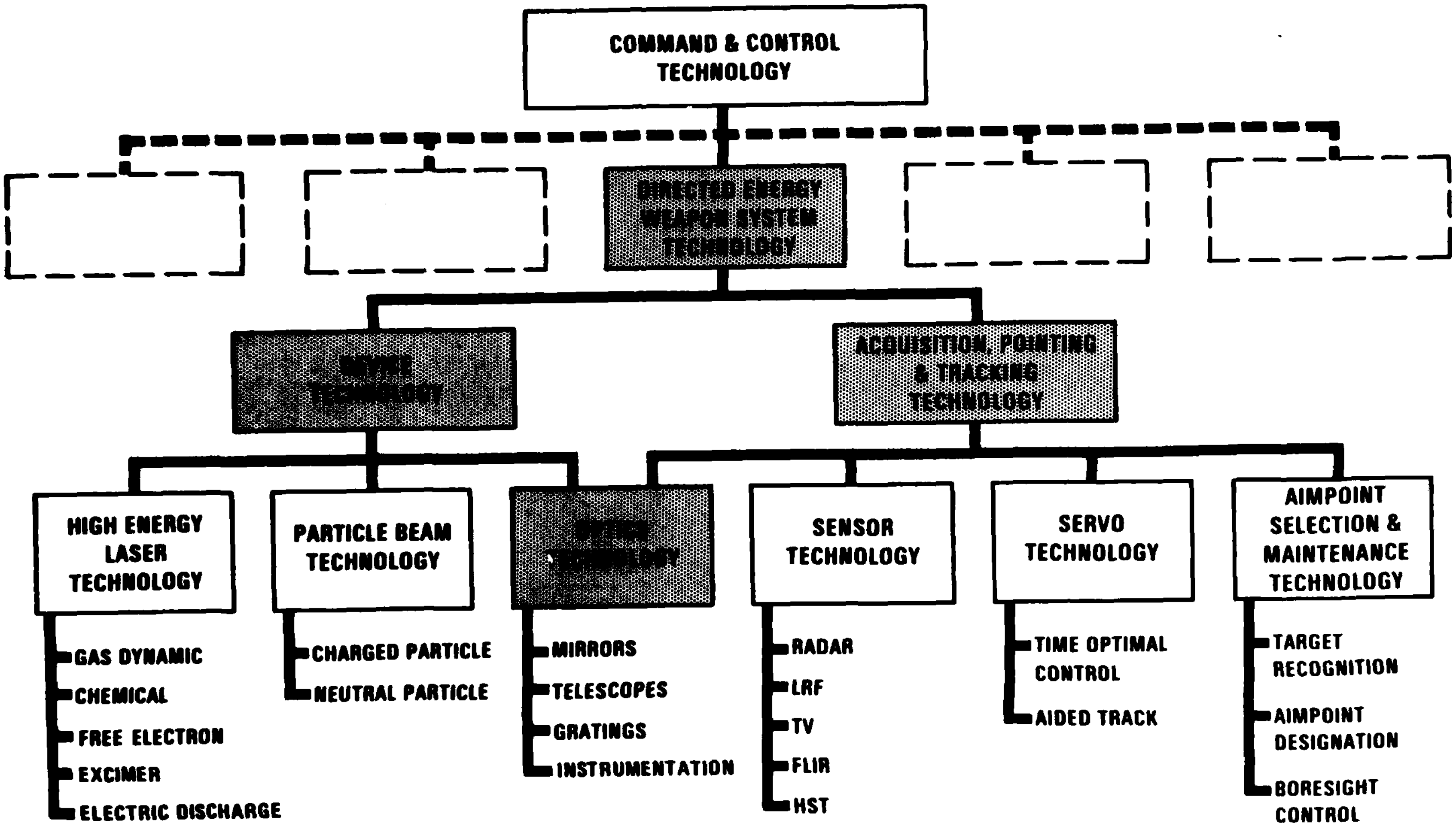


Figure 3-2: Directed Energy Weapon Systems Technology

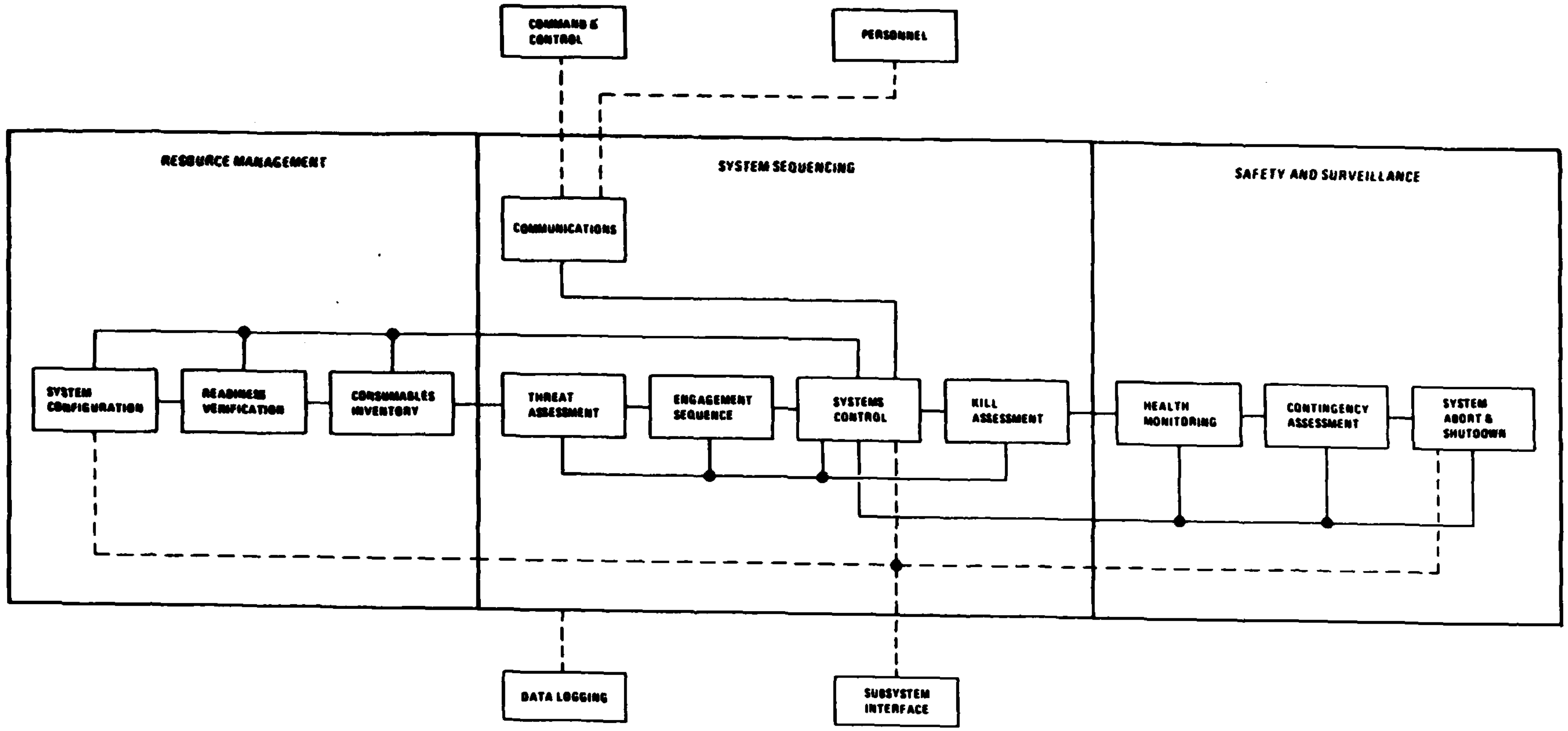


Figure 3-3: Weapon System Control Functional Block Diagram

3.1.1 Resource Management Functional Group

The resource management functional group consists of system configuration, readiness verification and consumables inventory functions. System interface configurations are established and tested by the system configuration function; subsystem set-up and readiness verification is performed by the readiness verification function; and consumables (fluids, gases, power, etc.) are managed by the consumables inventory function.

3.1.2 System Sequencing Functional Group

The system sequencing functional group consists of communications, threat assessment, engagement sequence, system control and kill assessment functions. This functional group interfaces directly with an external data logging function which records pertinent weapons system control data.

The communications function interfaces the system control function with external command/control and personnel functions. The system control function sequences other subsystems in accordance with an operational time-line (via an external subsystem interface function); it also initializes threat assessment, engagement sequence, and kill assessment functions during the engagement phase of a mission.

3.1.3 Safety and Surveillance Functional Group

This functional group consists of health monitoring, contingency assessment and system abort/shutdown functions. The health monitoring function monitors system operation for indications of system performance anomalies and potential hazardous conditions. This function interfaces with the contingency assessment and system control function to evaluate health monitoring safety messages and control system sequencing. The system abort and shutdown function, the subsystem control function and the external subsystem interface function for system aborts and orderly system shutdown.

3.2 Acquisition, Pointing and Tracking

The Acquisition, Pointing and Tracking Function is composed of four functional groups: the subsystem control and foresight selection group, the boresight establishment group, the boresight maintenance group and the boresight correction group. These functional relationships are shown in Figure 3-4.

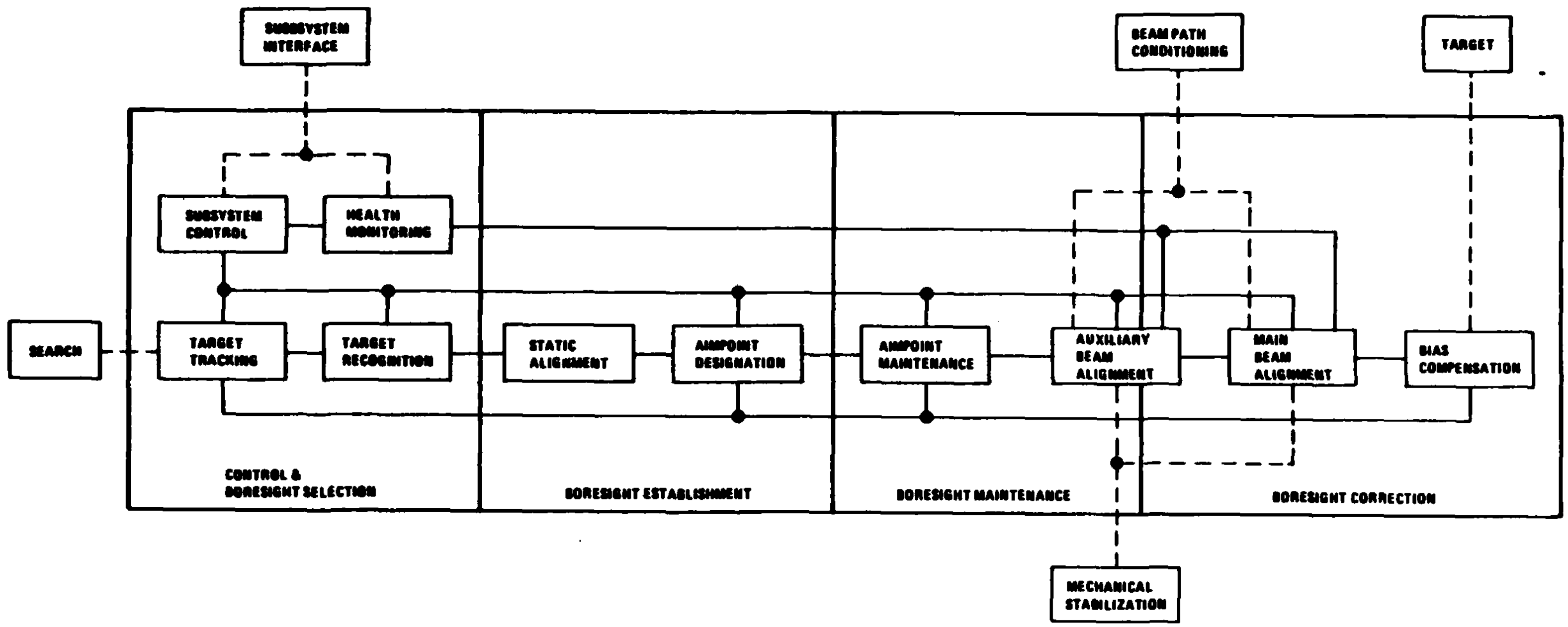


Figure 3-4: Acquisition Pointing and Tracking Functional Block Diagram

3.2.1 Subsystem Control and Boresight Selection Functional Group

The subsystem control, health monitoring, target tracking and target recognition functions constitute the subsystem control and boresight selection functional group. The subsystem control and health monitoring functions interface with the Weapon System Control Function (via an external interface function) for system sequencing and safety/surveillance functions, respectively. The health monitoring function monitors subsystem operations for indications of off-nominal performance, particularly with respect to active beam alignment functions, and the subsystem control function sequences subsystem functions in accordance with a mode sequencing regimen.

The tracking function accepts a handoff from an external search function and interfaces with a target recognition function for target identification.

3.2.2 Boresight Establishment Functional Group

The boresight establishment functional group consists of a static alignment and aimpoint designation function. The static alignment function is a distributed function which establishes the reference line-of-sight for the beam across system boundary planes. The aimpoint designation function establishes the line-of-sight from the exit aperture of the pointer/tracker to the target plane.

3.2.3 Boresight Maintenance Functional Group

The aimpoint maintenance and auxiliary beam alignment functions constitute the boresight maintenance functional group. The aimpoint maintenance function maintains the beam line-of-sight to the designated target aimpoint. An established boresight will drift, however, due to thermal gradients and transients, and it will also be disturbed by forcing functions that are not filtered out by the external mechanical stabilization function. It is the function of the auxiliary beam alignment function, therefore, to maintain the beam line-of-sight at the reference position established during static alignment. This function is initiated before main beam activation, and it is spatial distributed through the system.

3.2.4 Boresight Correction Functional Group

The boresight correction functional group consists of main beam alignment and bias compensation functions. The main beam alignment function uses a low power sample of the main beam to reduce dynamic beam motion, and it is capable of removing device induced wedging and flow field turbulence errors that cannot be detected by an auxiliary beam alignment function. The bias correction function is required to correct target plane beam aimpoint offset errors after the beam impacts the target.

3.3 Device

The device function consists of a fluid supplies group, a power supplies group, a gain medium generation group, an exhaust management group, and an instrumentation, controls, and displays group. These functional groups and associated interdependencies are shown in Figure 3-5.

3.3.1 Fluid Supplies Functional Group

This functional group provides all consumables for the laser device including any oxidizers or diluents. It includes laser gas constituents, fuel for power supplies coolants, and gases required for beam path conditioning.

The fluid supplies functional group interacts with the gain medium generator, the laser system controller, the pointer and tracker, and optics groups. It provides all of the consumables to each of these areas at specified mass flow rates, compositions, and temperatures. It interacts with the controller for sequencing, health monitoring, and, where appropriate, indications of hazardous conditions.

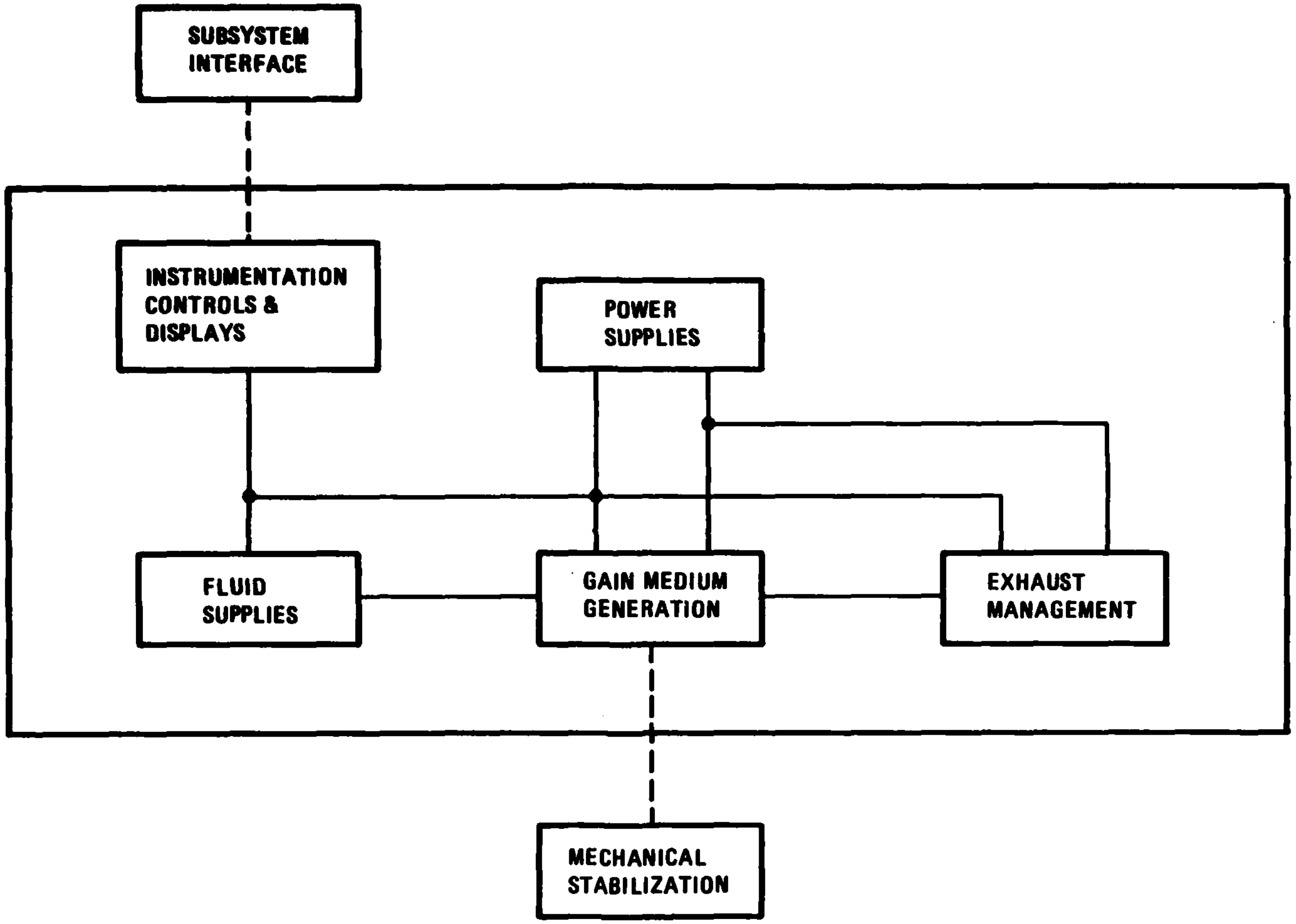


Figure 3-5 Device Functional Block Diagram

3.3.2 Power Supplies Functional Group

This group provides all power for system operation, including auxiliary power supply requirements. It interacts with the fluid supplies group, providing group enabling and shutdown capabilities. Depending on the particular laser type, it can also provide the power used for gain medium operation.

3,3.3 Gain Medium Generation Functional Group

This group contains all components required for the creation of a gain medium. It includes flow conditioning and excitation. Depending on the generic laser under consideration flow conditioning can include a combustion function, a supersonic expansion function, or a subsonic flow smoothing function. The excitation function can be the result of combustion and supersonic expansion or electric discharge pumping. The excitation function produces radiated energy that is contained in molecular excitation, and an external optics function outcouples a portion of this energy for transmission to the beam director.

3.3.4 Exhaust Management Functional Group

The precise functional requirements of this group depends on the generic laser. For a gas dynamic laser, it is principally one of pressure recovery to ambient pressure surroundings. For chemical lasers it includes both pressure recovery and effluent pumping functions. For an electric laser, it includes acoustic damping and for closed cycle operation, heat removal and compressor functions.

3.3.5 Instrumentation, Controls, and Displays Functional Groups

This group is subservient to the system controller for standby, fire, and stop fire commands. Beyond this, the IC&D group is entirely responsible for the control, and instrumentation of the laser device system. It provides all enabling and stop commands to all laser system functional groups, monitors the health and performance of each functional group, and where appropriate, displays this information.

3.4 Optics

The Optics consists of three functional groups: the beam generation functional group, the beam management and control functional group, and the beam delivery functional group. The interrelationship of these functional groups are shown in Figure 3-6.

The beam path conditioning function interfaces with specific optic functions to ensure a high degree of beam quality. The mechanical stabilization function interfaces with alignment functions to minimize the effects of vibration and acoustical noise on system performance.

3.4.1 Beam Generation Functional Group

The beam generation functional group contains four functions: feedback, magnification, scraping and media interface. These functions are closely associated with device gain medium generation functions which produce laser radiation.

The feedback function provides sufficient regenerative power to the gain medium to support optimum extraction of laser energy. The magnification function provides the gain medium and the necessary interface with the feedback function to achieve optimum extraction efficiency. The scraping function interfaces with the magnification function to develop the feedback power level and provides the necessary cavity outcoupling mechanism. The media interface function permits outcoupling of the laser beam to the beam management and control and beam delivery functional groups.

3.4.2 Beam Management and Control Functional Group

The beam management and control functional group consists of the following functions: subsystem control, health monitoring, shaping, wavefront management, steering, sizing and alignment functions.

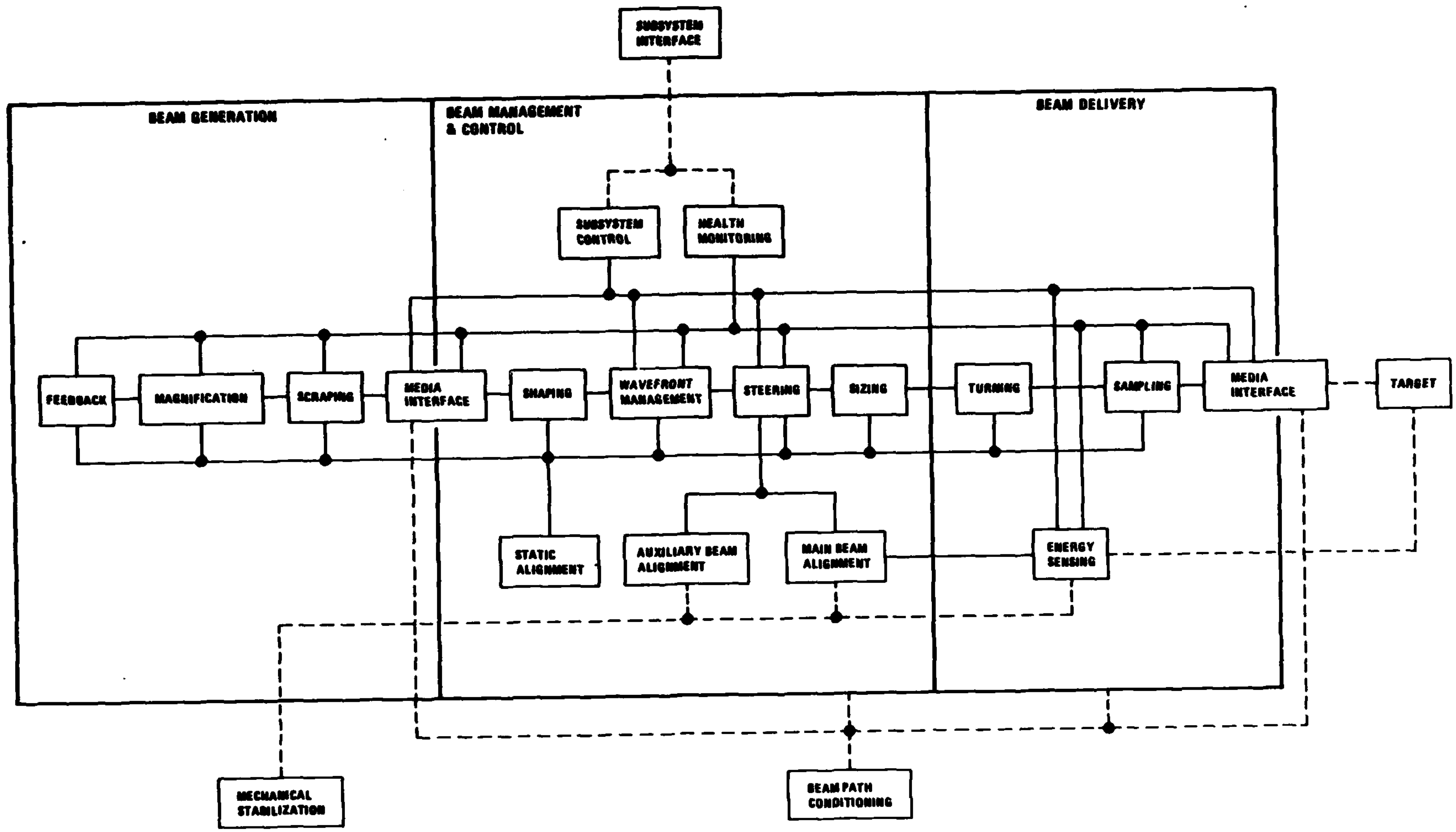


Figure 3-6 Optics Functional Block Diagram

The subsystem control and health monitoring functions interface with an external interface function for subsystem sequencing and safety/surveillance functions, respectively.

The alignment function consists of static, auxiliary beam and main beam alignment functions. Static alignment establishes the reference line-of-sight of the optical train, auxiliary beam alignment provides an automatic feedback alignment control function to minimize boresight errors, and main beam alignment uses a low power sample of the high energy beam to reduce beam dynamic motion.

In addition, the shaping function alters the beam dimensions in a radial, non-symmetric, fashion to optimize propagation efficiency; the wavefront management function provides the mechanisms by which higher order wavefront aberrations can be minimized or corrected; the steering function, the lowest order form of wavefront correction, power steering mirrors which respond to alignment function signals to correct residual tilt and/or off-axis propagation; and the sizing function symmetrically alters the beam (magnify/demagnify, clip, etc.) to reduce intensity loads, protect equipment, reduce thermal blooming, and maximize target irradiance.

3.4.3 Beam Delivery Functional Group

The beam delivery functional group consists of turning, sampling, media interface and energy sensing functions. The turning function permits optical train packaging in a space-limited environment, the sampling function redirects a portion of the laser beam for diagnostic purposes, and the media interface function optimizes the transfer of the beam from the beam director to the atmosphere. The energy receiving function senses return energy from the target and interfaces with the alignment function to provide closed-loop alignment control to the target plane.

3.5 Case Studies

Three case studies were analyzed to develop RMA models for use in support of working group investigations. These studies included a Tactical Open Ocean Carrier Task Force Anti-Ship Missile Defense System (ASMD) Scenario, a Strategic Airborne Sea-Launched Ballistic Missile (SLBM) Defense Scenario, and at Strategic Space-Based Anti-Ballistic Missile (ABM) Defense Scenario. These case studies are provided in Appendix A through C, respectively.

3.5.1 Open Ocean Carrier Task Force ASMD Scenario

This scenario deals with a multiple threat carrier task force engagement where the task force outer defense was penetrated and the Directed Energy Weapon System was to provide close-in weapon system support in self-defense of high-value units (e.g., carriers, fast combat support ships, etc.). A secondary mission was to also provide support defense for the remainder of the task force.

3.5.2 Airborne SLBM Defense Scenario

The Airborne SLBM Defense Scenario involves multiple threat SLBM engagements from an aircraft which is operating as an element of a Global Ballistic Missile Defense (GBMD) System. The GBMD is a three-tiered system dealing with early (boost), mid-flight and terminal phase engagements of SLBM's. It is the mission of the Directed Energy Weapon System to engage SLBM's in the boost phase of flight.

3.5.3 Spaced-Based ABM Defense Scenario

In this scenario, an orbiting battle station is operating as an element of GBMD System, and it is the mission of the Directed Energy Weapon System to provide outer zone anti-ballistic missile defense by engaging multiple threats in the boost phase flight.

SECTION 4

WEAPON SYSTEM CONTROL TECHNOLOGY

The main thrust of future weapon systems design activity must be directed toward the development of system architectures that address the complex integration of sensors, weapons and platforms. Three major areas of concern should be:

(1) Embedded computer resource development

(2) Improved data transmission and multiplexing techniques

(3) Operational training methods and techniques

Technological advances in these areas could result in significant payoffs in improved weapon system reliability, readiness and survivability.

4.1 Technology Description

As was described in Paragraph 3.1, the Weapons System Control Subsystem performs three major functions: resource management, system sequencing and safety/surveillance. The technology required to implement these functions already exists, and it imposes no serious problems to the ultimate development of a Directed Energy Weapon System.

Typically, the implementation of the weapon system control functions would result in a subsystem configuration as shown in Figure 4-1. Using present technology, such a configuration would consist of from 3000 to 6000 SSI/MSI/LSI chip types which would average about 60 gates per chip. These chips would be mounted on anywhere from 200 to 400 printed wiring boards, and they would be interconnected with 125 to 250 cable runs.

Table 4-1 indicates the present reliability that can be expected from a typical control system operating in a space, ground, shipboard or airborne environment. The failure rates for integrated circuits and connectors were developed using MIL-HBK-217D, Reliability Prediction of Electronic Equipment. These typical failure rates are shown in Table 4-2. The failure rates for the remaining subsystem assemblies were developed from existing control system performance data.

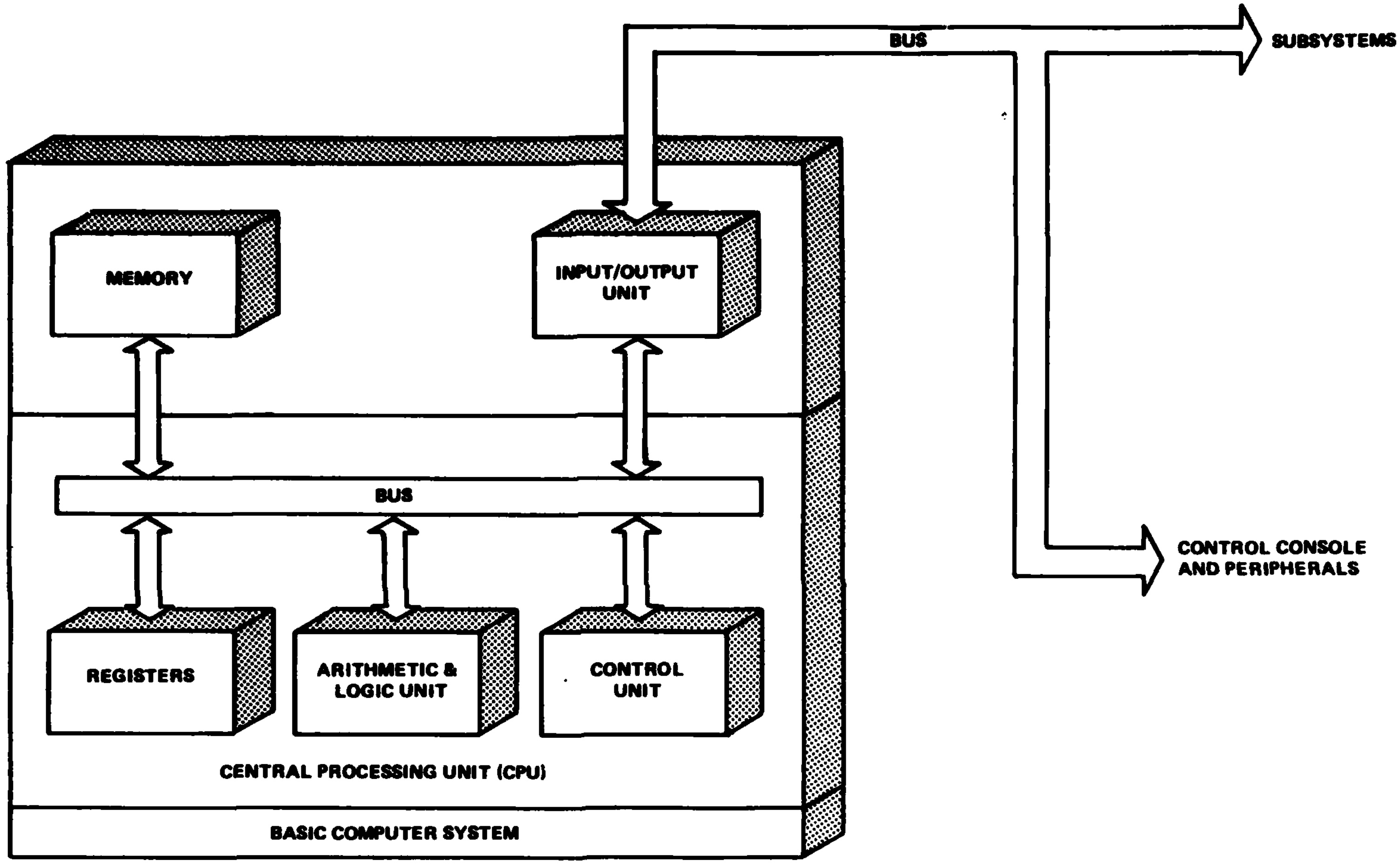


Figure 4-1: Elements of Weapon Control Subsystem

Table 4-1. Reliability of Present Control System Technology

ASSEMBLY	PRESENT FAILURE RATES - λ (FAILURES/MILLION HOURS)			
	SPACE	GROUND	SHIPBOARD	AIRBORNE
INTEGRATED CIRCUITS (6000)	60	180	300	360
CABLING AND CONNECTORS	4	40	100	110
DISPLAYS AND CONTROLS	-	60	70	80
MISCELLANEOUS HARDWARE (POWER SUPPLIES ETC.)	100	180	200	250
OTHER (SOFTWARE, ETC.)	50	50	50	50
TOTALS	214	510	720	850
MEAN-TIME-BETWEEN FAILURES (MTBF) - HOURS	4,673	1,960	1,389	1,176

Table 4-2. Typical Environmental Failure Rates (MIL-HBK-217D)

ASSEMBLY	TYPICAL FAILURE RATES - λ (FAILURES/MILLION HOURS)			
	SPACE	GROUND	SHIPBOARD	AIRBORNE
INTEGRATED CIRCUITS	0.01	0.03	0.05	0.06
PRINTED CIRCUIT BOARD CONNECTORS	0.003	0.03	0.07	0.08
CABLE CONNECTORS	0.006	0.03	0.14	0.15

The estimates of existing control system reliability shown in Táble 4-1 were then allocated to the three major functions of the Weapon System Control Subsystem. This allocation is provided in Table 4-3.

Table 4-4 summarizes the reliability and maintainability requirements for each of the case study scenarios that are provided in Appendice A, B and C. This information, in conjunction with the estimates of existing weapon system control reliability, provides the basis for identifiying what design areas may warrant improvement in the development of a Directed Energy Weapon System.

4.2 Potential Areas of R&M Improvement

Table 4-5 provides RMA assessments for the case studies presented in the appendices. Existing R&M estimates are compared with R&M allocations that are necessary to meet the objectives of each case study. In no case do the existing R&M values meet the allocated needs of individual case study scenarios. Current MTBF estimates fall short of allocations by factors of three to six; MMTR estimates must be reduced by a factor of one-third. It should also be pointed out that, although no repairs can be affected in spaceborne systems, the study indicates a need to address the reliability of dormant mode operations. These MTBF allocations are characteristically in the order of one-thousand times those of active mode operation.

4.3 High Pay-Off Support Technologies

Faced with the need to improve the reliability of the Weapon Control System by some five fold and decrease repair times by one-third, the question arises as to where the greatest potential for improvement can be found.

4.3.1 Reliability Gains

Reference to Table 4-1 indicates that major gains in reliability can be achieved through a reduction in microcircuit and cabling requirements. Two support technologies, VLSI/VHSIC and fiber optics hold promise for significant reliability improvements in this area.

Table 4-3. Functional Allocation of Existing Subsystem Requirements

FUNCTION	ENVIRONMENT							
	SPACE		GROUND		SHIPBOARD		AIRBORNE	
	λ	MTBF	λ	MTBF	λ	MTBF	λ	MTBF
RESOURCE MANAGEMENT	53	18,657	137	7,299	190	5,263	224	4,464
SYSTEM SEQUENCING	148	6,734	339	2,950	481	2,079	568	1,761
SAFETY AND SURVEILLANCE	13	77,519	34	29,412	49	20,408	58	17,241
TOTALS	214	4,673	510	1,960	720	1,389	850	1,176

Table 4-4. Functional Allocation of Future Subsystem Requirements

FUNCTION	ENVIRONMENT					
	SPACE		SHIPBOARD		AIRBORNE	
	STANDBY MTBF	ACTIVE MTBF	MTBF	MTTR	MTBF	MTTR
RESOURCE MANAGEMENT	51,813,000	51,813	30,303	1	19,763	2
SYSTEM SEQUENCING	18,519,000	18,519	11,976	1	7,794	2
SAFETY AND SURVEILLANCE	212,766,000	212,766	117,646	1	76,336	2
SUBSYSTEM	12,800,000	12,800	8,000	1	5,200	2

VLSI/VHSIC will reduce the overall chip count by increasing throughput (speed) and the number of logic gates per chip. By way of example, assume that all but 25% of the microcircuit functions can be replaced by VLSI/VHSIC, 4500 present day chips can be replaced by some 14 VLSI/VHSIC, 4500 present day chips can be replaced by some 14 VLSI/VHSIC chips. Using the VLSI/VHSIC chip reliability goal of 0.06 failures per million hours of operation, the shipboard integrated circuit failure rate, for example, would be reduced to 76 failures per million hours that is estimated for present technology. Concomitant with the chip count reduction would be a board count decrease of 75% which directly results in a similar reduction in board connector failures.

Fiber optics can be employed to realize further gains in cable performance. Fiber optics provide significant improvements over conventional transmission media. These improvements include:

(1) Noise immunity and short-circuit protection

(2) Light weight, low volume and wide bandwidth

(3) High temperature operation

The wide bandwidth will permit a reduction in the number of cables needed to support the Weapon Control System. A 25% reduction would be a conservative estimate. Using this percentage reduction, the shipboard cable failure rate could be reduced to 50 failures per million hours.

The aforementioned improvements for the shipboard system example would amount to 453 failures per million hours (down from 720). Because these improvements are still unsufficient to reach the 8,000 hour goal of the shipbaord scenario, circuit redundancy would have to provide the remaining improvement. It should also be pointed out that, although redundancy could have satisfied the entire 8,000 hour goal, the reductions in subsystem size and complexity afforded by VLSI/VHSIC and fiber optics make redundancy all the more practical. In the shipboard example, all but the displays and controls could be made redundant. This would provide a Weapon Control System MTBF of 8330 hours (1/120 failures per million hours of operation).

Although this MTBF meets the shipboard scenario allocation of 8000 hours, it can be seen that software failures now assume a major proporation of the reliability budget. Indeed the effect of unreliable software may increase

Table 4-5. RMA Comparison (Existing Versus Required)

FUNCTION	ENVIRONMENT											
	SPACE				SHIPBOARD				AIRBORNE			
	STANDBY MTBF (HRS)		ACTIVE MTBF (HRS)		MTBF (HRS)		MTTR (HRS)		MTBF (HRS)		MTTR (HRS)	
	ALLOCATED	EXISTING	ALLOCATED	EXISTING	ALLOCATED	EXISTENG	ALLOCATED	EXISTING	ALLOCATED	EXISTING	ALLCOATED	EXISTING
RESOURCE MANAGEMENT	51,813,000	UNK	51,813	18,657	30,303	5,263	1.00	1.56	19,763	4,464	2.00	3.00
SYSTEM SEQUENCING	18,519,000	UNK	18,519	6,734	11,976	2,079	1.00	1.60	7,794	1,761	2.00	3.00
SAFETY & SURVEILLANCE	212,766,000	UNK	212,766	77,519	117,646	20,408	1.00	1.72	76,336	17,241	2.00	3.50
SUBSYSTEM ALLOCATION	12,800,000		12,800		8,000		1.00		5,200		2.00	

as a result of providing redundancy. At this point, it may be appropriate to discuss what is meant by unreliable software. Unlike hardware, software does not breakdown, deteriorate or wear out. When software failure occurs, it is usually because the software has been exposed to conditions for which it was not designed nor tested. That is to say, either the design was incorrectly or incompletely specified in the program performance or design specification, or the implementation was in error. The use of a structured approach to computer programming holds considerable promise for eliminating many of the software problems that have been attributed to implementation errors, particularly if a standard high-order language (HOL) is used in confunction with a standard computer instruction set.

4.3.2 Maintainability Gains

Maintainability gains are of equal importance as reliability gains for shipboard and airborne scenarios. The VLSI/VHSIC technology is expected to reduce diagnostic checkout and fault isolation through the increased use of built-in test (BIT) and built-in-test equipment (BITE). Moreover, reductions in equipment volume should materially improve access and removal times. Further improvements must come from manpower and training technology. Increased emphasis on operator performance and material condition monitoring, coupled with two-level maintenance concepts, should result in lower repair times and reduced maintenance loads.

4.4 RMA Assessment

This section is devoted to assessing Weapon System Control Subsystem improvements resulting from the use of selected new technologies for each of the three case study scenarios provided in the appendices.

4.4.1 Open Ocean Carrier Force (ASMD) Case Study

The expected improvements to be gained for the Weapon System Control Subsystem are provied in Table 4-6 through 4-8. The applicable technology, description of the improvements, predicted increases in the MTBF, and decreases in the MTTR are given with respect to major subsystem functions.

(1) Resource Management Function

The MTBF of 5,263 hours and MTTR of 1.56 hours for the Resource Management Function were improved to 8,801 hours and 1.03 hours, respectively. The impact of each technology is provided in Table 4-6.

Table 4-6. Resource Management Function Improvements (Shipboard)

NEW TECHNOLOGY	ΔMTBF	Δ MTTR
VHSIC	3,145	0.30
Fiber Optics	197	-
Operational Software	196	-
Manpower & Training	-	0.23
TOTALS	3,538 hours	0.53 hours

(2) System Sequencing Function

The MTBF of 2,079 hours and MTTR of 1.60 hours for the System Sequencing Function were improved to 3,417 hours and 1.04 hours, respectively. The impact of each technology is provided in Table 4-7.

Table 4-7. System Sequencing Function Improvements (Shipboard)

NEW TECHNOLOGY	Δ MTBF	Δ MTTR
VHSIC	1,195	0.32
Fiber Optics	80	-
Operational Software	63	-
Manpower & Training	-	0.24
TOTALS	1,338 hours	0.56 hours

(3) Safety and Surveillance Function

The MTBF of 20,408 hours and MTTR of 1.70 hours for the Safety and Surveillance Function were improved to 20,802 hours and 1.10 hours, respectively. The impact of each technology is provided in Table 4-8.

Table 4-8. Safety and Surveillance Function Improvements (Shipboard)

NEW TECHNOLOGY	Δ MTBF	Δ MTTR
VHSIC	348	0.34
Fiber Optics	31	-
Operational Software	15	-
Manpower & Training	-	-
TOTALS	394 hours	0.60 hours

Factoring these new technology improvements into the overall Weapon System Control subsystem results in the 2,201 hour MTBF and a 1.04 MTTR. Although the MTTR meets the scenario requirement, the MTBF falls short of the 8,000 hour requirements. Further improvement can only be achieved through redundancy. The volumetric reduction to the subsystem attained through the use of new technologies will make redundancy more practical. If all but the displays and controls are made redundant 9,302 hour MTBF can be achieved.

4.4.2 Airborne Sea-Launched Ballistic Missile (SLBM) Defense Case Study

The predicted improvements resulting from the use of selected new technologies are provided in Tables 4-9 through 4-11. The applicable technology, description of improvements, predicted increases in MTBF, and decreases in MTTR are given with respect to major subsystem functions.

(1) The MTBF of 4,464 hours and MTTR of 3.12 hours for the Resource Management Function were improved to 7,120 hours and 2.02 hours, respectively. The impact of each technology is provided in Table 4-9.

Table 4-9. Resource Management Improvements (Airborne)

NEW TECHNOLOGY	Δ MTBF	Δ MTTR
VHSIC	2,399	0.63
Fiber Optics	146	-
Operational Software	111	-
Manpower and Training	-	0.47
TOTALS	2,656	1.10

(2) System Sequencing Function

The MTBF of 1,761 hours and MTTR of 3.2 hours for the System Sequencing Function were improved to 2,891 hours and 2.08 hours, respectively. The impact of each technology is provided in Table 4-10.

Table 4-10. System Sequencing Function Improvements (Airborne)

NEW TECHNOLOGY	Δ MTBF	Δ MTTR
VHSIC	1,022	0.64
Fiber Optics	63	-
Operational Software	45	-
Manpower and Training	-	0.48
TOTALS	1,130	1.12

(3) Safety and Surveillance Function

The MTBF of 17,241 hours and MTTR of 3.4 hours for the Safety and Surveillance Function were improved to 24,071 hours and 2.3 hours, respectively. The impact of each technology is provided in Table 4-11.

Table 4-11. Safety and Surveillance Function Improvements (Airborne)

NEW TECHNOLOGY	Δ MTBF	Δ MTTR
VHSIC	6,128	0.68
Fiber Optics	495	-
Operational Software	207	-
Manpower and Training	-	0.51
TOTALS	6,830	1.19

The overall effect of these improvements on the Weapon System Control Subsystem is an MTBF of 1,894 hours and an MTTE of 2.08 hours. As in the ASMD Case Study, redundancy is necessary to achieve the required MTBF, and the volumetric reductions afforded by the aforementioned technologies make this a practical and viable consideration.

4.4.3 Space-Based Anti-Ballistic Missile (ABM) Defense Case Study

Reference to the space-based case study indicates that the standby reliability (MTBF) requirements are a thousand times more stingent than the active reliability requirements. Although little is known about dormant failure modes in Directed Energy Weapon System equipment, compendia such as MIL-HBK-217D imply a factor of one-tenth the active failure rate is applicable to dormant or low power modes of operation. As a result, it is concluded that a considerable amount of redundancy will be required to achieve space-based reliability allocations. Redundancy, however, can be relatively inefficient without a repair capability (not practical in space), that is unless it can be accomplished at the circuit/module level where fault detection and correction methods many be implemented.

Consider the Weapon System Control Subsystem for example. Assuming that the standby failure rates are one-tenth that of the active failure rates, the probability of successful operation (in a dormant or low power mode), over the five year operating life is as shown in Table 4-12.

Table 4-12. Probability of Successful Operation (Dormant/Low Power Mode)

SUBSYSTEM FUNCTION	Ps
Resource Management	0.92
System Sequencing	0.79
Safety and Surveillance	0.98

Further suppose that these three functions can be made redundant as shown in Figure 4-2. Configuration (A) reflects no redundancy, and it would experience a limited probability of success (Ps) of 0.71 which is far below the case study requirement of 0.9966. Configuration (B), on the other hand, represents a simple approach to redundancy, where the entire Weapon Control Subsystem is

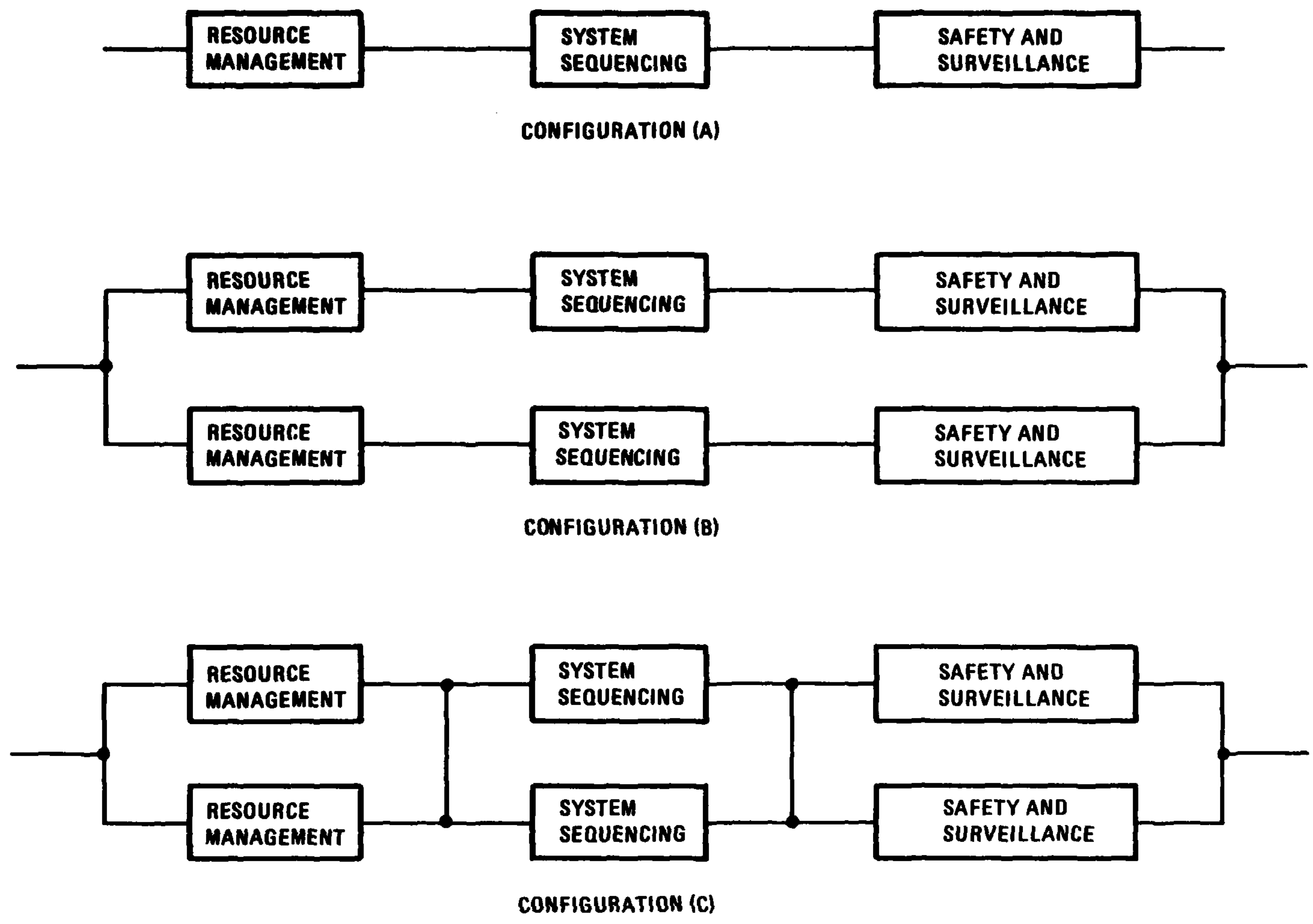


Figure 4-2. Weapon System Control Redundancy Configurations

duplicated. In this case, a failure will result in subsystem operation being sustained (one time only) by switching to the redundant subsystem. This configuration will yield a Ps of 0.90. Configuration (C) reflects a further refinement to redundancy where individual subsystem functions may be switched if a failure occurs. This configuration will provide a Ps of 0.93.

It is apparent from this analyses, that more complex and sophisticated approaches to achieving fault tolerant and redundant designs for space-based applications will be required. If reliability goals similar to those present in the space-based case study are to be achieved. This fact is increasingly apparent when the practicality of redundant designs are considered for device, optics and pointer-tracker functions.

4.5 Conclusions

It is believed that required improvements in overall weapon systems control effectiveness can be achieved through the judicious application of recent technological advances in embedded computer performance, data transmission and multiplexing techniques, and overall weapon systems operational training.

4.5.1 Embedded Computer Resources

The use of embedded computer resources (including software) in future weapon system designs must be more effectively managed if the overall effectiveness of control systems are to be improved and escalating life-cycle costs are to be continued.

A number of technological advances, including significant breakthroughs in microelectronics, have made possible the creation of smaller and faster machines that are well-suited for weapon systems applications. In particular, very large-scale integration (VLSI) and very high-speed integrated circuits (VHSIC) technology is being developed with increasing success, and this progress will have a far-reaching impact on computer architecture, operations and logistics support. These developments are resulting in a much wider use of distributed processing techniques, and because inherent high-order language (HOL) inefficiencies in speed and memory utilization can be substantially offset through improved computer hardware performance, a much broader application of HOL's is evolving.

These successes, however, mandate that more effective testing tools and facilities be developed for embedded computer hardware/software systems, and that they be considered in the very initial stages of system development.

4.5.1.1 VLSI and VHSIC

Extensive utilization of VLSI and VHSIC is key to achieving the embedded computer performance required for future weapon system designs. Of equal importance, however, is the requirement to better understand and implement computer aided techniques at all levels of computer system design and test.

As the development of integrated circuits have increased in complexity, computer aided design (CAD) techniques have played an increasingly important role in minimizing design iterations while introducing a high degree of accuracy and reliability to the design process. As further improvements in integrated circuit design continue to evolve, the dependence on CAD is not only unequivocal and irrevocable, it must be extended to include computer aided test development (CATD).

CATD provides the key to rapid exploitation of VSLI and VHSIC for embedded computer systems. Since the computer "knows" all of the input-output combinations, all BIT structures, and where all the extremely inaccessible subcircuits are embedded, it is capable of evaluating all logic paths and associated timing functions. More importantly this data base can be effectively used by the computer to develop test software concurrent with the design of an integrated circuit.

4.5.1.2 High-Order Language (HOL) Standardization

The use of an approved common high-order language for embedded computer systems can be a major factor in improving weapon system effectiveness and reducing life-cycle costs.

In its efforts to improve software standards, the DoD has undertaken the development of a new programming language called Ada. As an HOL, however, Ada is not without problems or limitation. It has been designed for a broad range of applications, and as a consequence, it may not satisfy the needs of all weapon system application. In addition, existing computer systems have considerable software assets in other languages, and conversion to Ada may not always be feasible or practical. These problems, however, should not be permitted to subvert the underlaying need for a more universal approach to software design and computer programming.

It is imperative, therefore, that the DoD persist in its efforts to adopt a common HOL for future military applications. This standardization initiative will undoubtedly encounter transitional difficulties, but the continued proliferation of embedded computer resources can only exacerbate an already intolerable situation. In so doing, however, a reasonable and flexible posture should be adopted with respect to implementation so that both present and future needs can be satisfied as efficiently and effectively as possible

4.5.1.3 Instruction Set Architecture (ISA) Standardization

ISA standardization can have also have a considerable impact in improving weapon system operational readiness. Standardization could enhance interchangeability, relaibility, maintainability, and overall logistics support. It could also reduce design risks by specifying items, processes and practices, and it could conserve money, manpower, time and facilities required to test, maintain and repair embedded processor resources.

HOL standardization, in conjunction with an ISA that permits efficient compilation of code, could also reduce software development risks, provide an extensive transportable software base, and reduce life-cycle cost through improved software maintenance. These factors undoubtedly would have a significant impact on overall weapon system effectiveness.

4.5.2 Data Transmission and Multiplexing Techniques

Improvements in data transmission and multiplexing techniques could also have a significant impact on overall weapon system readiness. Major benefits to be derived from these techniques include:

(1) Reduced space and weight

(2) Increased reliability and survivability (automatic bus reconfiguration and redundancy)

(3) Improved maintainability resulting from automatic fault detection, isolation and correction (BITE).

(4) Increase design flexibility and supportability through the use of modular design concepts

(5) Reduced life-cycle cost through data bus standardization

Considerable work is required in the development and evaluation of data transmission and multiplexing technology for advanced weapon system designs. Military standards must be established for space, ground, shipboard and airborne applications, and technologies that could contribute significiently to the overall effectiveness of data bus techniques must be exploited. Two such technologies include VLSI/VHSIC and fiber otpics.

Specific advantages of VLSI/VHSIC are increased processing throughput with reductions in size, weight and power consumption. Packaging, mil-spec performance (especially in the -55°C to +125°C range with failure rate equal to or less than 0.1% per thousand hours at 125°C), and radiation hardening, however, represent technical challenges that must be met for military application.

Fiber optic technology also offer significant advantages for improved weapon system readiness and reliability. Such advantages include:

(1) Electrical isolation and short-circuit protection

(2) Reduced EMI/RFI emission and susceptibility

(3) Wide bandwidth

(4) Light weight and low volume

Considerable effort is required, however, in the development of mil-standards for transmitter devices, receiver devices, optical switches, optical repeaters, cables and connectors

4.5.3 Operational Training Methods and Techniques

ISA, HOL and data transmission and multiplexing standarization could have an appreciable impact in reducing the skill levels required to maintain complex control systems.

In addition, the use of built-in-test (BIT) techniques and associated technologies (VLSI/VHSIC) to enhance operational safety, reduce maintenance time, and improve overall weapon system effectiveness should be a key objective for future weapon system designs. Specific action should be taken in the design process to ensure that:

(1) Fault detection probability is consistent with the mission requirements and the design goals (specifications) for the system

(2) BIT demonstration tests model the operational environment

(3) False indications and nuisance alarms are minimized, and the reliability of the system is not compromized

(4) Requirements for skilled technicians are minimized

Reductions in skills levels are synonomous with a change in emphasis from system maintenance to system operation and performance monitoring. This change in emphasis will require a continued reordering of training priorities, including the need for more sophisticated operational trainers and simulators.

SECTION 5

ACQUISITION, POINTING AND TRACKING TECHNOLOGY

5.1 Technology Description

The acquisition, pointing and tracking technology is represented by practices that have been used and are being used in many weapon systems. It is assumed for the high energy laser system under consideration that these functions will be fulfilled by optical activities. The acquisition will be accomplished by a passive system, presumably in the infra red. The pointing and tracking capability will be accomplished by a passive system, although an optical radar is also a candidate system. Most of these capabilities have previously been used in existing systems and are reasonably reliable; however, with the application to high energy laser systems, in particular, there are several additional operational capabilities that will cause some uncertainties in the R&M performance.

In the high energy laser application it is required that for pointing and tracking capability the aperture be shared with the high energy laser beam. This introduces into the problem the question of how can the high energy beam and the tracking beam be separated. In addition, for the correction of phase instabilities introduced into the outgoing beam either by the laser, or intervening optics, or by the turbulent atmosphere and blooming of the atmosphere by the high energy beam, a means must be provided for measuring the phase of the beam and correcting for the observed aberrations in the beam. Research efforts are now underway to investigate the best techniques for making these measurements.

For the case of a relatively small, intense high energy laser beam, coupled with a target that will be resolved by the tracking beam, it will be necessary to point the beam to a preselected aimpoint on the target. The method of selecting the means for identifying the target, selecting an aimpoint, and holding the aimpoint throughout the time of illumination is the subject of on-going investigation.

Finally, although much research is being put into the effort, the development of cooled detector arrays for the acquisition system, or the pointing and tracking system, continues to add uncertainty to the R&M performance of the system.

5.2 Potential Design Areas for R&M Improvement

The design of systems with cooled detector arrays can lead to an impaired R&M performance. A cooled array can lead to improved sensitivity in the infra red but potentially at the expense of system R&M performance. The current research is attempting to develop warm detectors with improved sensitivity, in general, but has, at the present time, lead to a deterioration of system R&M performance. A choice for the system could be to change the wavelength at which acquisition or pointing and tracking are done, but, depending on the system application, that may not be an appropriate choice.

Detector lifetime is strongly dependent on the properties of a particular detector including materials and fabrication or processing techniques. In some cases deterioration occurs on the shelf as well as for detectors in operation, as in the case of some HgCdTe detectors. High resistivity photo diodes are particularly susceptible to performance deterioration. On the other hand, the lifetime of high D* detectors for low background applications may be on the order of a few years at present. In the building of large arrays it is the realization of a better performance in terms of the percentage of operating detectors that is of interest.

The selection of the appropriate choice for the aperture sharing device for adaptive optics is still in the research and development stage. It is not clear which route to select at the present time; however, it appears that one of the buried grating techniques will turn out to be satisfactory. If it is not, an alternate would be to operate with a pulsed system and do the tracking in the interpulse interval, or to do offset apertures, or some other technique.

The adaptive optics system is likewise in a research and development stage at present. Techniques are currently still being developed for sampling the phase across the wavefront. The techniques for accomplishing the correction are also still under investigation. It is, therefore, difficult to suggest a particular technique that should be adopted. Suffice it to say that the

the technique, in one form or another, will improve the performance of any high energy laser system.

The choice of technique for identifying the target, for selecting an aimpoint and maintaining the aimpoint is also still in a developmental state. The ultimate performance of this portion of the system will be considerably influenced by the development of artificial intelligence techniques and by very high speed integrated circuit techniques.

5.3 High Pay-Off Support Technologies

The detector arrays could benefit from development work in the area of sensitive warm detectors or in the area of very reliable closed cycle cooling systems. Similarly, the adaptive optics sensing and correction system would benefit from an expanded effort in solid state integrated optics activity. The aimpoint selection and maintenance efforts would benefit considerably from the development of artificial intelligence and the very high speed integrated circuit developments.

5.4 RMA Assessment

It is, perhaps, premature to attempt an assessment of the RMA at this time. Until the developments in each of these activities are further along and judgements can be made with respect to the performance of alternate techniques that are under development, it may not be appropriate to make an RMA assessment.

5.5 Conclusion

The overall system of acquisition, pointing and tracking may be in fairly good condition with the exception of several additions that are required specifically for high energy laser systems. These include cooled detector arrays for acquisition or pointing and tracking, aperture sharing techniques for the high energy laser beam, adaptive optics measurements and corrections, and techniques for selecting and maintaining the aimpoint during irradiation. These additions can be developed through the research and development currently underway in cooled arrays, aperture sharing techniques, adaptive optics capabilities and artificial intellligence and very high speed integrated circuit developments.

SECTION 6

DEVICE TECHNOLOGY

6.1 Technology Description

There are several types of high energy laser devices, including gas dynamic lasers, chemical lasers, and electric lasers, each one offering unique advantages which are strongly application dependent. However, because of limited resources it has only been possible to examine in any depth one class of high energy laser, the electric discharge laser. Further, this has been limited to E-beam electric lasers.

6.1.1 E-beam Laser Operation and Ranges of Output Wavelengths

As stated, the generic laser device examined in this section is an E-beam laser. E-beam in this case is meant to include E-beam sustained, E-beam pumped, and E-beam initiated. Each application requires a high energy ($>$100 KV) broad area electron beam with pulse lengths variations from a few microseconds to continuous operation and current density variations from milliamps to amps/cm^2. Changes in gun design are required to accommodate the pulse length and current density variations. However, there are a sufficient number of common elements for all applications that it is considered reasonable to neglect these differences for the objectives of this study. The common elements include an electron emitter, a vacuum source, a thin window or foil which transmits electrons but maintains vacuum integrity, high voltage control, and high voltage power supplies.

6.1.1.1 E-beam Sustained Lasers

E-beam sustained lasers utilize the E-beam to maintain discharge ionization while an independent or sustainer source pumps the major portion of the electrical energy into the lasing volume. Figure 1 provides a schematic representation of this approach. Considerable research and device development has been performed on E-beam sustained lasers. It has covered CO_2 (10.6μ output) and CO (5μ output) lasing mixtures in both continuous wave and repetively pulsed waveforms. Rep rates up to 500 hz and multikilojoule outputs have been demonstrated in CO_2.

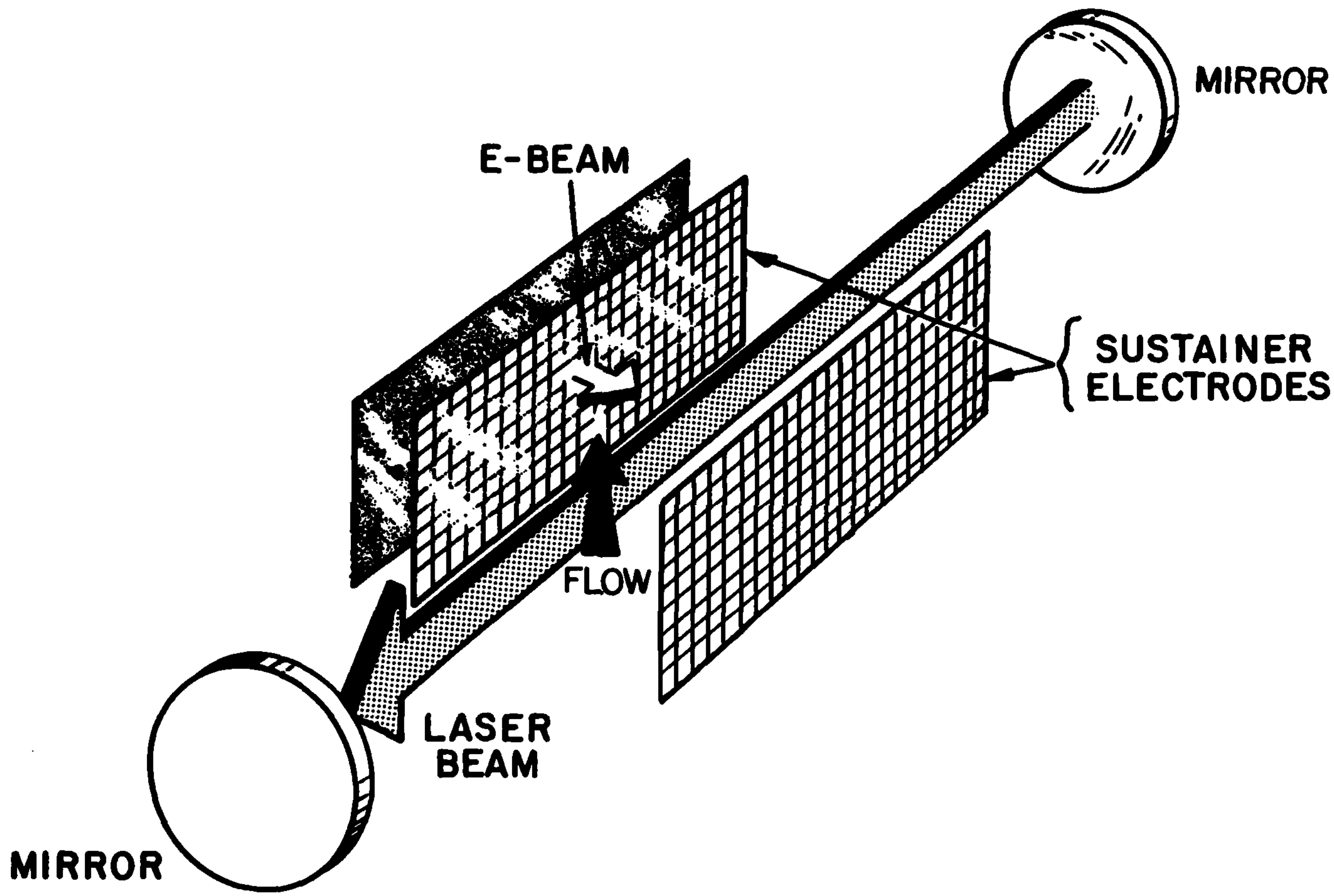


Figure 6-1: Electric Discharge Laser Configuration

6.1.1.2 E-Beam Initiated Device

E-beam initiated devices are typified by pulsed chemical lasers wherein pulse high energy electrons are used to uniformly initiate a chemical reaction. The specifics of the chemical reaction determine the output laser characteristics, but several microsecond pulses at 3.8μ have been demonstrated. Research and development efforts in pulsed chemical lasers have not been as intense or continuous as for CO_2 so that the technology base is not fully developed.

6.1.1.3 E-beam Pumped Lasers

E-beam pumped lasers include excimer laser systems that can operate in the visible and UV. As such they represent primary candidates for strategic laser weapon system applications. In this mode of operation the E-beam is the primary source of input energy and thus extremely high levels of current density are required. While the subject of research for only a few years considerable progress has been made in E-beam development and device technology.

6.1.2 Major Subsystems

6.1.2.1 E-beam

The E-beam includes the electron emitter, vacuum box, vacuum system, control system and the foil and foil support structure.

6.1.2.2 Flow Channel

The flow channel covers all of the components and subsystems associated with the laser cavity, flow conditioning and acoustic attenuation. The laser cavity includes whatever confinement methods, such as magnetic field, are used to control E-beam spreading. Flow conditioning includes inlet flow preparation, boundary layer control where appropriate, and downstream flow treatment. Acoustic attenuation is necessary for all high energy pulsed lasers operating at $\geq$10 hz when good beam quality is required.

6.1.2.3 Fluid Supply System

The fluid supply includes the appropriate storage and delivery systems for the lasing cavity gas, beam path conditioning gas, and pneumatic system fluids. For closed cycle operation it also includes compressors and heat exchangers.

6.1.2.4 Electric Supplies

Electric supplies encompasses all power supplies and power conditioning. The electric supplies subsystem for pulsed laser operation is more complex than for continuous wave output laser operation. The pulsed power conditioning equipment must be added which generally includes high voltage magnetics, high energy density capacitors, and high voltage and current switches.

6.1.2.5 Instrumentation, Controls and Display

The laser IC&D package is subservient to a master system controller or fire control system for standby, fire and stop fire commands. Beyond this, the laser IC&D is considered capable of handling all control functions for the laser device. It also contains the necessary instrumentation and display functions to provide built in test capability, as well as continuous monitoring of system health.

6.2 Potential Design Areas for R&M Improvement

In lieu of a fielded high energy laser weapon system it is difficult to assess, with thoroughness, design areas for R&M improvement to determine those subsystems or components that most adversely effect system reliability. The preponderance of experience is with hardware designed for proof of principal, a laboratory environment.

R&M efforts can be used profitably to facilitate the transfer of high energy EDL technology from laboratory devices to reliable field devices. This can be accomplished in two ways: detailed analysis of available laboratory data and development of components/subsystems. The principle purpose of the data examination would be to separate those areas which would benefit primarily from technological advances from those which would benefit primarily from engineering development. The second part would implement programs to provide the needed technology or engineering development. The second part would implement programs to provide the

the needed technology or engineering development. A few specific examples are listed below:

(1) High Voltage/High Coulomb Switches

Such switches are used in pulsed power conditioning assemblies. For low rep rate application spark gaps appear to be the most reliable approach. However, reliable operation at high voltages (in excess of 500KV) has yet to be demonstrated. The availability of such switches would greatly impact the development of high energy excimer lasers.

At high repetition rates (in excess of 100 hz), thyratrons are generally used. Thyratron conductivity is electrically controlled and therefore capable of high repetition rates. Spark gaps are only turned on electically. Fluid mechanic flushing of the conductive region is required before subjecting the spark gap to high voltage. The combination of high voltage stand off and rep rate is thus gas flow dependent. Thyratrons have demonstrated poor reliability when operated from a cold start. For radar systems this characteristic is overcome by running the thyratrons in, by letting them misfire. For high energy lasers the pulse energy can be substantial, so that running in per se may not be acceptable. Development of thyratrons capable of reliable cold start operation would increase device reliability.

(2) Pulse Forming Networks

Regardless of whether the particular device is E-beam sustained, initiated, or pumped, a pulse forming network is required to supply input energy. The requirements vary in pulse length, from a few to tens of microseconds, and energy, from a few to tens of kilojoules. Little efforts has been devoted to PFN packaging which would reduce volume and increase component accessiblity while increasing reliability. To date, most PFN's built have been for laboratory units and as such are not compatible with fieldable applications.

- The payoffs for such R&M engineering development efforts would impact both contemplated tactical and strategic laser weapon system applications. For tactical applications in tracked vehicles, space is at a premimum. In certain strategic applications PFN output voltages in excess of 500 KV will be required. Oil is generally used to provide high voltage stand off at these voltage levels. Packaging and accessibility again become crucial issues.

(3) Pulsed Laser Optical Component Coatings

Experience to date on mirrors and transmitting elements has illustrated the difficulty of finding coatings which can handle pulsed laser radiation. Pulse peak fluxes greatly accentuate slight imperfections in coatings, causing local damage cites to develop. In fact, there have been no coatings or pulsed laser optics which have been able to survive operating levels of incidence fluence for more than a few pulses at 10.6μ .

The availability of coatings which could survive pulse laser radiation and which would reduce mirror losses would increase system performance. Laser system output would be increased and mirror cooling requirements would be decreased.

6.3 High Pay-Off Support Technologies

Technological advances in subsystem and component performance promises the greatest payoffs for future high energy weapon systems. In point of fact, conceptual design studies based on state-of-the-art component technologies (for example, prime power or capacitor storage energy densities) cannot accommodate available weight and volume allocations in desired delivery vehicles and still meet mission requirements. While considerable effort has been expended over the past decade on laser device technology development, little has been spent on subsystem component development. Thus, for example, electric laser discharge performance has been extremely well characterized, but a reliable compact prime high power source to compliment this performance has yet to be developed.

6.3.1 Testing Technology

Clearly, to achieve reliability performance values commensurated with almost any weapon system application it will be necessary to regularly update laser system status in the field, isolate components that may have failed, and quickly replace them. Improvements in testing technology, in particular, built in test capability, will greatly facilitate this process. Further, performance updates that minimize man-in-the-loop requirements are desirable.

6.3.2 Operational Computers/Software

Some payoffs in increased performance, reliability and decreased weight and volume can be expected. Much bigger payoffs will be realized in the beam control and fire control areas which require processing equipment to identify targets, provide pointing information, maintain tracking and perform device alignment. Larger capacity memories in higher density are required.

6.3.3 Manpower and Training

The degree of training required to service and/or operate a laser weapon system will equal or surpass many existing deployed weapon systems. Training techniques and simulations, which facilitate understanding and improve services or operating techniques, will undoubtedly provide high payoffs in the future.

The fielding of high energy laser weapon systems will expose service personnel to new and unique components which require new and specific servicing techniques. One example is high energy/power mirrors and their associated cooling systems and environmental protection systems.

6.3.4 Non-Destructive Testing

Techniques and procedures which increase the ability to test components and subassemblies during assembly and system operation will increase system reliability. This will be particularly true in the non device areas such as fire control and beam control.

6.3.5 Cabling and Connectors

High voltage cables and high voltage terminations are critical components of electric lasers. Advances in these areas that increase flexibility and decrease volume requirements will be beneficial to system packaging.

Advances in high voltage stand off bushings will also increase electric laser reliability. Such bushings are used to support the inner E-beam box (electron generator) within the E-beam vacuum box. They must provide rigid mechanical integrity and high voltage stand off. Present techniques use an alternating structure of metal and ceramic rings mounted in compression. While acceptable for laboratory use, such designs will need improvements (both in design and in materials) to withstand shock and vibration loads introduced through standard off road transportation.

6.3.6 Fiber Optics

Fiber optics are used to provide communications between all of the subsystems of an electric laser because of high voltage isolation and electromagnetic shielding requirements. Increased fiber optics performance capabilities should not be expected to have a significant impact on laser system performance or reliability because they have not proven to be a critical item in performance reliability. The effect of fiber optics will be reflected in the increased EMI capability of the system and in the reduction of weight/volume with respect to copper conduction.

6.3.7 Packaging and Interconnect Modules

A very critical element in achieving acceptable levels of laser system success probability is the ability to achieve decreased mean times to repair. To date, high energy laser packaging has been dictated by technology requirements, not repair requirements. Advances in this area are critical.

6.3.8 Mechanical Systems Condition Monitor

Another critical element in achieving acceptable levels of laser system success probability is the ability to monitor and assess the health of each subsystem. This should be expanded to include electrical as well as mechanical systems.

6.3.9 Power Supplies

As stated earlier, the area of power supplies is key to the deployment of electric laser weapon systems. State-of-the-art capabilities do not support high energy laser weapon system deployment, particularly in tactical situations. This includes weight, volume, and demonstrated reliability. The power supplies heading is taken to include prime power, high voltage magnetics, capacitors, and switches.

6.3.10 Diagnostics

The determination of laser system health may require the development of new diagnostic techniques. For example, determination of mirror figure, output beam quality, or the implementation of countermeasures.

6.3.11 Computer Aided Design/Manufacturing (CAD/CAM)

Considering the complex nature of high energy laser systems, the application of CAD/CAM to their design and manufacture should provide significant benefits. Again, in lieu of an existing weapon system, it is difficult to quantitatively assess the impact of CAD/CAM.

The use of CAD will effectively decrease the design time by mechanizing the design procedure and utilizing specific software analyses such as: finite element analysis, high voltage isolation, form-fitting, mechanical alignment and effects of vibration, to determine the effectivity of a design change. The compatibility of the design may therefore be quickly analyzed and corrected.

6.3.12 Composites

Implementation of existing composite material technology to laser system design should provide considerable improvement in system performance and weight and volume packaging. To date, only conceptual designs have employed the benefits of composite materials.

6.3.13 Robotics

Specific benefits of robotics on laser weapon systems are difficult to project at this point in time. It is expected, however, that robotics can enhance, not only system performance, but system maintenance and repair.

6.4 RMA Assessment

It is considered premature at this time to attempt an RMA assessment of laser devices. Until a concerted effort is made to field a particular high energy laser weapon system, and until the technology and engineering development activities required to field such a system are completed, RMA assessments are not deemed appropriate.

6.5 Conclusions

High energy lasers have yet to take that rather large step from laboratory devices to fielded weapon systems. As such the R&M recommendations for the laser device centers as much on making this transition as on making future laser weapon systems reliable and easily maintained.

To facilitate the laboratory to field transition a two pronged program has been recommended. One prong is to provide a critical assessment of device reliability based on laboratory performance, segregating those areas that would benefit primarily from technology advances from those that would benefit primarily from engineering development. The second prong is to provide the necessary technology or engineering development programs to address the areas so identified.

Advances in high payoff support technologies are considered essential to the evolution of laser weapon systems. In several areas state-of-the-art component technologies cannot accommodate available weight and volume allocations and simultaneously meet mission performance requirements. Outstanding examples of this are prime power sources and capacitor storage energy densities.

SECTION 7

OPTICS TECHNOLOGY

7.1 Technology Description

Optics technology as it applies to the laser system is concentrated on the efficient transformation of the raw molecular energy within the device into the ordered optical energy that is then transmitted to a target or far-field spatial location designated by external control systems. To accomplish this task several optical technologies must be simultaneously in effect to ensure the performance capability, or reliability of the system. These technologies deal more with the operational or engineering aspects of the laser system because for this study the system is assumed to operate within the designed performance specifications. What is of concern here is the ability of the system to function as a weapon. Consequently, we have defined a weapon failure (whether the system is operating or not) as the inability of the system to deposit sufficient energy on the target within a specified period of time so as to obtain a target response pre-defined as "threat negation".

The optical assembly functions related to the operational or engineering aspects of the system and that are the basis for the RMA evaluation are discussed in the following paragraphs.

7.1.1 Mirror Reflectance

High Energy laser mirror reflectivity must be kept at a very high level or the temperature of the coatings at the interface of the coating and the reflecting surface will reach a level sufficient to destroy the coating. Reflectivity is typically required to be 99.5% or more. High efficiency coatings, such as are required to obtain these high levels of reflectivity, are relatively delicate and easily damaged by thermal overloads. Temperature limits are typically 200° to 300°F. Contamination from dust or other sources can also provide the mechanism by which a failure may occur. The contaminent absords energy and will burn thus directly causing damage to the coating. This small spot leads very quickly to the failure of the entire surface in what might be observed as a domino effect.

In evaluating the failure rate of coatings it was necessary to consider two environments. One within the resonator is more likely to contribute to failure of the coatings because the atmosphere generated by the device is essentially in contact with the mirror surfaces. There are several characteristics of the atmosphere generated by the device that may contribute to coating failure. Corrosive gases and particulate matter are examples. The other environment is outside the resonator and is, up to the transmitting telescope, protected from contaminants. Within the telescope itself the environment may be as in the beam transfer section or at least purged. Failure rates, then, are different for the two.

7.1.2 Mirror Heat Exchanger (HEX)

Mirror reliability is dependent on the mirror HEX functioning properly. When the HEX fails, the mirror cannot be purged of its absorbed energy and it fails catastrophically in a very short time (less than 0.5 seconds). HEX failure may occur through mechanical failure of bond/braze joints due to age, corrosion, stress/strain, or overpressure. The HEX may also fail functionally by not cooling at the design rate thereby allowing thermal buildup. This could be caused by blockage of coolant passages a failure of the coolant supply system.

One failure rate is estimated for mirror HEX. This rate includes all the above possibilities.

7.1.3 Mirror Mechanical Support

Each mirror element is supported in its spatial position by a mechanical structure that provides up to six degrees of remote adjustment freedom for the mirror, stability control, and ease of mirror across and exchange. Failure of this support can cause the mirror to become unaligned to a degree that compensation by other mirrors is impossible. These failures are infrequent, but are related to bearings, drive mechanisms, DOF locks and simple failures from stress/strain due to mechanical loads.

7.1.4 Beam Path Conditioning System (BPCS)

Two basic types of BPCS exist for endoatmospheric systems. One is designated vacuum because it is of the same pressure as the optical cavity within the device. The second is designated non-vacuum. Exoatmospheric systems would use a BPCS bit it would be functionally different and would not be expected to cause system failure if the BPCS functionally quit or degraded. The failures of the endoatmospheric BPCS systems could potentially cause enough thermal blooming within the BPCS to cause serious damage to equipment, alignment abort circuits to be activated, and such deterioration of the beam to render it unmanageable at the exit aperture so that is could not be considered effective at the target plane. Failures of BPCS functions would be evidenced in system leaks that contaminate the vacuum sections, leaks or contamination of gases within the non-vacuum sections, and purge control functions producing turbulence within the beam path anywhere in the system.

7.1.5 Window, Non-Material

The principle method of transferring an HEL beam from one pressured or conditioned atmosphere to another is to utilize a window at the interface. A window is a mechanism by which the beam can be transmitted but the medium on either side of the window cannot. Because HEL's typically do not use material windows, except perhaps at the exit aperture of the P-T, this evaluation will consider only non-material windows at all locations of environmental separation. Failures in this function are related to the transmission of the beam. Assuming leakage of one medium to the other is taken care of in the BPCS section, only beam transmission failures will be considered here. Non-material windows fail in the mechanical aspects of the window such as nozzle or plenum or diffuser, and they fail in the supply system providing the pressurized gasses that form the environmental barrier through which the beam is allowed to pass. These failures then lead directly to transmission failures by changing the refractive index in the window area.

7.1.6 Alignment System

The alignment function will always be a very complex interactive system that has, in most system designs, the capability to fail the weapon function. In this evaluation we will assume the alignment system, while critical to optimum effectiveness at the target, will be considered fail safe in that the weapon beam will still be able to traverse the system in a caged or return-to-center mode or be rerouted automatically to an emergency beam path to get useful energy to the transmitter. The alignment system is comprised of several loops that all get tied together to the target and to common references. Typically the loops are the resonator, the beam train loop, the pointer/tracker loop, the target loop, and the common or system loop. Failures can occur in any of these loops are most often confined to sensor/reference problems, the signal linkage between sensors and controls, or the mirror drives. Signal problems will be covered in the control sections and mirror drives were covered in the mirror support section. Sensor/reference failures are related to false electrical signals, scattered light and misaligned low power optical train. These cause the alignment to degrade or fail.

7.1.7 Optic Assembly Interfaces

The major interfaces addressed in this evaluation are the device, the vehicle/platform, and the external control system. The device can effect performance in terms of power, mode, and uniformity. Typically these will be seen as a very guarded degradation and typically will not constitute a failure. The vehicle/platform interface is generally related to facility services and course system alignment. The facility service will be considered here and problems involve power supply, spatial references, fluid supplies, maintenance, and other support services. Failures can be of many types, but are critical in the power supply and fluid supply areas. However, other than the interface itself and the distribution system within the optical assembly the failures in these areas are accounted for elsewhere in this evaluation. The external control interface provides control, direction, target data, and general system feedback. This interface will not be considered in this section as it is covered under controls.

7.1.8 Controls

After assurance of being able to get the laser beam from the source end of the laser to the exit aperture, the next concern is if it can be used. This is the responsibility, in large part, of the control system. In this regard the control system provides for wavefront distortion measurement and correction, power loss monitor and correction or abort, jitter measurement and control, beam characteristic measurement and maintenance, system component health and maintenance, all instrumentation and diagnostics, and all the on-line maintenance of the optical assembly. Use of fail safe technology is extensive in this area. Failures do occur however, but are most critical in the hazard, health, and abort system. This function depends on valid data on which to base the critical decision of abort or do not abort. The failures relate primarily to false signals and can be caused by voltage sources, electrical noise or signal interrupts.

7.2 Potential Design Areas for RM Improvement

In this section two points of emphasis are addressed. One is system performance improvement in terms of reducing required time on target thereby reducing operational time-line demands on the system. This is sensed directly as a payoff because it directly effects the reliability of the system. Since R (reliability) = $e^{-t/MTBF}$, and performance improvement reduces "t", then R more nearly approaches 1.0. The other point of emphasis, deals with those areas of reliability improvement that are generic to all systems. In this case, of course, they are specifically applied to the optics assembly. In this category you will find the usual terms, redundant, simplify, division of responsibility, etc.

7.2.1 Multi-Mission Concepts

The idea lowers life-time costs, standardizes design, and creates a less complex system. The laser weapon can benefit from this approach by placing emphasis on generic technology. Filter out those requirements that really need specialized technology and "commonise" the rest.

Some specific areas that have pay off potential are:

- o Multi-wavelength optics - coatings that allow efficient operations at more than one wavelength.
- o Variable apertures - some missions are best served with other than the largest transmitting apertures.
- o Shared apertures - all wavelengths should be able to use same path in both directions.

7.2.2 Reliability Improvements

Potential areas providing reliability improvements by improving system performances are:

- o Beam sampling - lower efficiencies, less distortion of both sample and sampled beam.
- o Active Steering - very high frequency bandwidth for control mirrors.
- o Wavefront correction - improved resolution of control optics; improved OPD's in optical gain medium.

7.2.3 Availability Improvements

Deployed weapon systems are useful for their intended purpose only during a specific time period. This time period is referred to as the system availability. If MTBF and MTTR factors are both known, then the Availability may be calculated as the ratio of MTBF to the quantitiy MTBF plus MTTR. This ratio is termed inherent availability. The inherent availability assumes the RMA cycle of the sytem contains only three factors; the time between failures, the fact that a failure exists, and the time it takes to restore the system to useful status. Many systems, and especially an optical system, actually have one additional factor. This factor is called scheduled maintenance and can have a significant impact on availability. Including this factor in the availability equation modifies inherent availability to demand availability. Figure 7-1 depicts the impact of maintenance of system availability. For present optical systems the ratio of scheduled maintenance time to RAM cycle time is between 1/1 and 1/2- obviously unacceptable for any operational system.

Optical system scheduled maintenance requirements for present laser systems are related to all functions within the system Mirrors require continuous visual and operational checks to verify cleanliness of surfaces, functionality of cleaning purges and coolant system, filter condition, adjustment freedom and bearing lubrication, surface deformation, and mount integrity. The beam path conditioning system requires flow checks, interior surface condition checks, filter cleanliness verification vibration isolator freedom verification, and verification of leak-free joints and seals. The alignment system requires recalibration following each run and trend data analyzed for

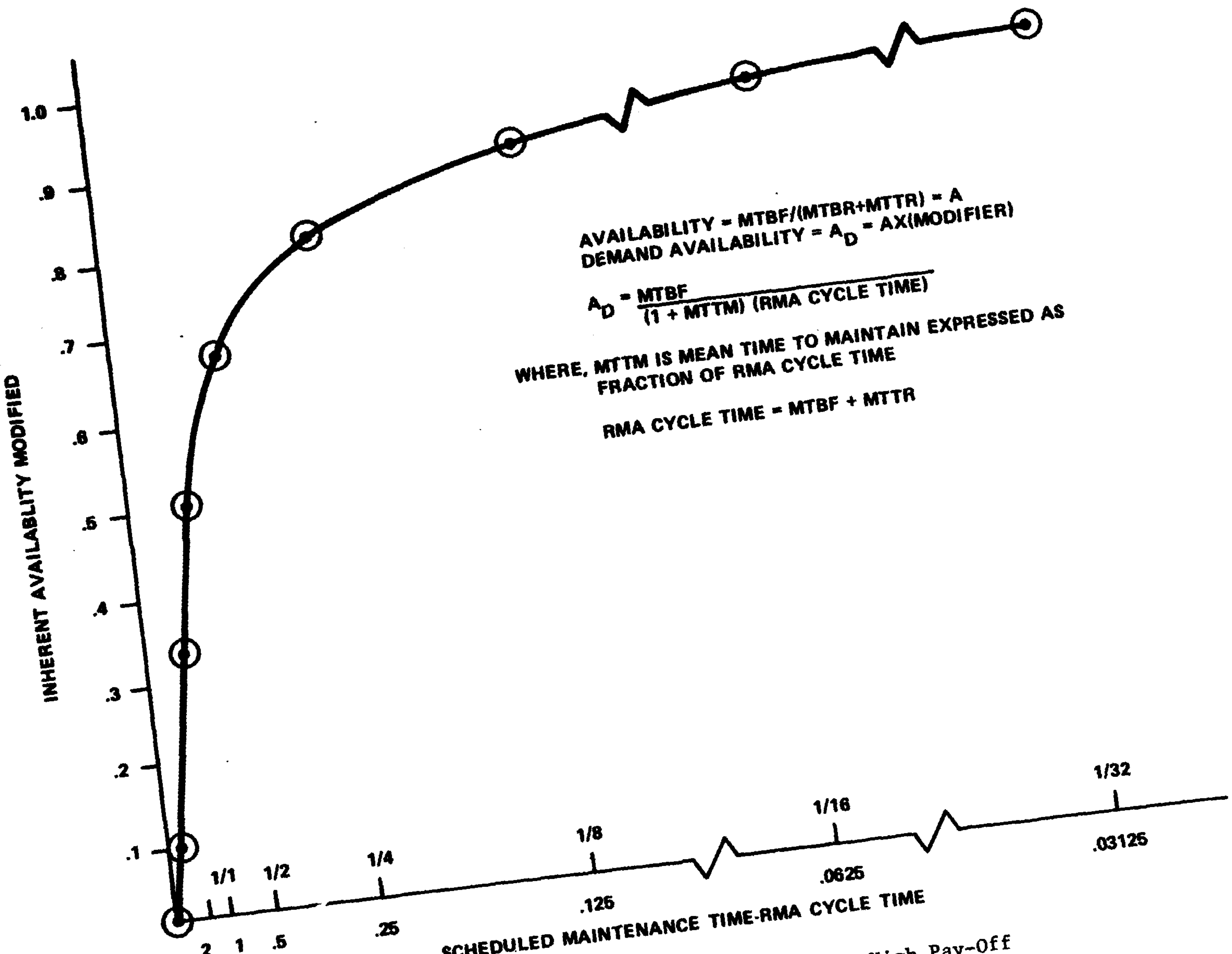


Figure 7-1. Reduce On-Line Maintenance Time for High Pay-Off

possible trouble indications. Controls and diagnostic requires frequent sensor checks and calibration. Deformable mirrors require verification and correction of null surface condition. Other elements of the system have similar requirements.

It is projected that the ratio of scheduled maintenance time to RMA cycle time can improve to 1/8 for the first generation operational system. To achieve even this level will require emphasis on maintainability throughout the detailed design and development phases of the first generation system. To achieve the demand availability goal desired for a mature weapons system concept will require the use of advanced support techologies discussed throughout this report.

The major functions of a generic optical system are shown in Table 7-1 along with the MTTR failures associated with these functions. By reducing the MTTR significantly (factors of 10 to 40) through design attention to maintainability, the availability will be significantly improved. Because of the improved speed with which parts/components can be replaced the scheduled maintenance concept will also change. Parts/components will be quickly removed and replaced, returning the system to available status. The scheduled maintenance would then be done off-line with no further impact on system availability. This concept, in conjunction with design/development improvements using advanced technologies to reduce scheduled maintenance, must be pursued vigorously to make the DEWS viable.

The advanced technologies with potential for high payoff in improved availability are a combination of Artificial Intelligence, Robotics, Diagnostics/Prognostics and VHSIC. These technologies could be combined to a) sense whether maintenance was required, b) determine what needs the maintenance c) perform the maintenance quickly with little human involvement and return the system to available/operational status.

7.2.4 General Areas of Improvement

(1) Maturation process - systems need to mature faster as personnel can be trained faster and remain trained longer. This implies simplication and dependability but really means understandable systems.

AD-A137 332 DIRECTED ENERGY TECHNOLOGY WORKING GROUP REPORT (IDA/OSD R&M (INSTITUTE F..(U) INSTITUTE FOR DEFENSE ANALYSES ALEXANDRIA VA SCIENCE AND TECH.. B R MAYO 2/2

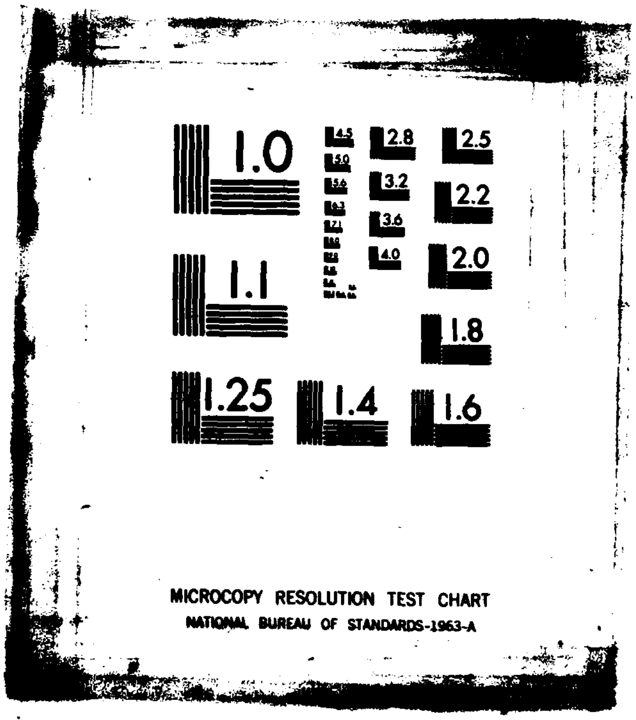
UNCLASSIFIED AUG 83 IDA-D-32 IDA/HQ-83-25898 F/G 15/3 NL

END

FILMED

3-84

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 7-1. Summary, Optics System RMA Assessment

ITEMS PER FUNCTION	MAJOR FUNCTION	MTTR EXPECTED	MTTR EXISTING
8	MIRROR-COATING	.25	4
8	MIRROR-HEX	.25	4
8	MIRROR-STRUCTURE	.25	4
2	BEAM PATH CONDITIONING	.35	8
1	WINDOW-TRANSMISSION	.50	10
5	ALIGNMENT	.10	2
3	DEVICE INTERFACE	8	80
3	P/T INTERFACE	2	40
2	ACTIVE CORRECTION	.50	5
2	QUALITY MAINT.	.1	2
4	SYS. MONITOR	.2	8
4	CONTROL SYS.	.1	2

(2) Beam quality maintenance - once a high quality beam is produced, many degrading processes occur. Need improvement in

- coatings
- mirror cooling
- component stability
- beam paths

(3) Data and technology base development - need to develop ability to reliably predict effectiveness.

7.3 High Payoff Support Technologies

The 15 support technologies (other than optics) being studied by the Technology Working Group will be discussed in this section as to what significant payoffs could results from direct effort within these technologies.

7.3.1 Very High Speed Integrated Circuits

Optical Control systems will require very high control rates for deformable mirrors and the sensors they respond to. Sensor arrays 1000 x 1000 will be used to real-time monitor and control beam wavefronts. Payoff is difficult to evaluate. Anything that allows another photon to get to the aimpoint is an improvement.

7.3.2 Testing Technology

Need development and implementation of testing technologies that allow realistic evaluation of operational realiability. Also need methodologies to determine what tests are actually required to ensure required performance. Present reliability predicting techniques are antiquated.

7.3.3 Software

Need system self-diagnosing, self-healing, and self-adjust capabilities for optic assembly. But real need in software is to have it perform its own production, debug correction, and implementation. Special areas of attention should be test planning/procedures for calibration, performance evaluation, reliability predictions, learn from feedback etc.

7.3.4 Artificial Intelligence

Controversial but potentially a very high payoff area. Relates to the software requirements in Pargarph 7.3.3. Need to address control of robots in maintaining laser optical systems. Needs to learn from success and failure. Requires very high speed processes. Needs ability to perform automatically and near-instantaneous preventive maintenance.

7.3.5 Cabling/Connectors

Any improvement will help but attention should be placed on designing the common connector and cable. Standardization is already in place but the number of standards can be reduced dramatically when it comes to weapon systems.

7.3.6 Fiber Optics

EMI is a very serious problem for electrical systems. Fiber optics eliminates the concern. Need applications of fiber optics in the control of laser systems. Improve quality transmission characteristics.

7.3.7 Packaging and Interconnect Modules

Self-check, self-maintenance, etc., or designed to be serviced by robots.

7.3.8 Power Supplies

Really the heart of any system that has any non-static element. Laser systems, and especially optics, needs improvements in stability, capacity, size, weight, shelf life, etc.

7.3.9 Diagnostics

Need simple, accurate, versatile wavefront analyzer. In general, need an approach that integrates the needs of the reliable laser weapon. Diagnostics must change the emphasis to PROGNOSIS. The system must be able to sense its own pulse and anticipate its needs well in advance of a failure that renders useless the system that has set, supposedly, at a ready - until needed. This then will provide significant payoff.

7.3.10 Composites

Need metering structure for optical assemblies that are non-outgassing and self-correcting for their undesirable material characteristics. Another area of composite material application is high energy laser mirrors - especially very large mirrors like telescope primaries. These mirrors would be light weight, dimensionally and mechanically stable, tolerant of the environment, and would not propagate to other parts of the mirror localized damage received from KE projectiles.

7.3.11 Robotics

Need to combine this technology with AI, controls, diagnostic, CAD/CAM, and software to come up with the integrated appraoch to 100% reliability in weapons systems.

7.4 RMA Assessments

Three case studies are included in the optics system - RM evaluation. These are:

Case Study #1 - OBL/ASMD
Case Study #2 - ABL/SLBM
Case Study #3 - SBL/ABMD

Case #1

Reliability Phase - 10 minutes
Engagement Phase - 10 minutes

Case #2

Reliability Phase - 6 hours
Engagement Phase - 10 minutes

Case #3

Reliability Phase - 5 years
Engagement Phase - 4 minutes

Tables 7-2 and 7-3 provide RMA summary data for the shipboard case study.

Table 7-2. Optical Subsystem RMA Assessment (Shipboard)

APPLICABLE TECHNOLOGY	DESCRIPTION OF IMPROVEMENT (AND FUNCTION REFERENCE NUMBER)		PREDICTED IMPROVEMENT TO REFERENCED FUNCTION	
			MTBF	MTTR
VHSIC	INCREASE THROUGHPUT AND REAL TIME SIGNAL/DATA PROCESSING	(7)		
VHSIC	INCREASE THROUGHPUT AND REAL TIME SIGNAL/DATA PROCESSING	(9)		
TEST TECH	ALLOW REALISTIC EVALUATION OF OPERATIONAL RELIABILITY	(ALL)		
SOFTWARE	ADA IMPLEMENTATION AND UPGRADES TO SELF-DIAGNOSTICS/ CORRECTION, AND CAPABILITY OF PLAN/PROCEDURE GENERATION	(ALL)		
MANPOWER & TRAINING	IMPROVE MAN/SYSTEM UNDERSTANDING	(ALL)		
ARTIFICIAL INTELLIGENCE	IMPLEMENT INTEGRATED MAINTENANCE PHILOSOPHY	(ALL)		
CABLING/CONNECTORS	IMPLEMENT DIRECTED ENERGY WEAPON STANDARD	(5-9)		
FIBER OPTICS	IMPROVED *QUALITY TRANSMISSION (GYRO)*	(7-9)		
PACKAGING/INTER-CONNECT MODULES	IMPLEMENT SELF-CHECK, SELF-MAINTENANCE	(5-9)		
MECH SYS COND. MON.	IMPLEMENT IMPROVEMENTS	(ALL)	UNK	UNK
POWER SUPPLIES	IMPLEMENT IMPROVEMENTS	(3-9)	UNK	UNK
DIAGNOSTICS	IMPLEMENT PROGNOSIS CAPABILITY	(ALL)		
CAD/CAM	IMPLEMENT INTEGRATED DESIGN/MAINTENANCE PHILOSOPHY	(ALL)		
COMPOSITES	DEVELOP SELF-CORRECTING METERING STRUCTURES	(ALL)		
ROBOTICS	IMPLEMENT INTEGRATED DESIGN/MAINTENANCE PHILOSOPHY	(ALL)		

Table 7-3. Optical Subsystem RMA Improvement (Shipboard)

REFERENCE NO.	MTBF		MTTR	
	ALLOCATED	EXISTING	ALLOCATED	EXISTING
1 MIRROR REFLECTANCE (RES)	5000 (.99997)	1000 (.9990)	.25	4
2 MIRROR REFLECTANCE (TRAIN)	5000 (.99997)	2000 (.9990)	.25	4
3 MIRROR HEX	10000 (.99998)	10000 (.99998)	.25	4
4 MIRROR SUPPORT	14000 (.99998)	14000 (.99998)	.25	4
5 BPCS	18000 (.99998)	2000 (.9995)	.35	8
6 WINDOW	18000 (.99999)	10000 (.99998)	.50	10
7 ALIGNMENT	8000 (.999979)	1000 (.9998)	.10	2
8 INTERFACES	10000 (.99998)	6000 (.99997)	.80	80
9 CONTROLS	12000 (.999996)	1000 (.9998)	.10	8
TOTAL	(.99996)	(.9994)		

7.5 Conclusions

The most difficult element of the RM study has been to separate the technologies study into individually needed and appreciated groups. The solution to the RM problem is an integrated system undivided by arbitrarily defined technological boundaries. Interplay and overlap must be enhanced intelligently to ensure all "technologies" are properly dovetailed so as to realize a synergostic solution.

Specific improvements in optics RMA are:

Near Term

- o Develop rapid restoration techniques
- o Reduce on-line maintenance requirements
- o Develop automatic and remote repair technologies

Long Term

- o Develop robotics and artificial intelligence technologies
- o Develop Maintenance Concept Methodology/Plan
  - system requirements
  - system time lines
  - maintenance time lines
  - technology requirements

SECTION 8

RECOMMENDATIONS TO TECHNOLOGY STEERING GROUP

Based on the results of this study, a number of specific recommendations have been formulated for follow-up by the Technology Steering Group. These recommendations are based on a current understanding of Directed Energy Weapon System Technology, and what are perceived to be high pay-off actions that could be taken in the near-term to enhance the probability of achieving and adequate level of system readiness and reliability in future weapon system applications.

8.1 System

(1) System management and engineering discipline must be invoked and enforced throughout the acquisition cycle of any new Directed Energy Weapon System. This process will ensure that R&M considerations are adequately addressed in the procurement, design, fabrication and operational phase of development, and it will provide the means by which cost schedule and performance can be adequately controlled.

(2) A study should be commissioned to address the suitability of scaling and packaging directed energy weapon system designs for specific weapon system applications (space ground, shipboard and airborne), as deemed appropriate by the DoD.

(3) A study should also be conducted to address the impacts of atmospheric, meteorological, platform environment and countermeasures on Directed Energy Weapon System performance for specific applications (space, ground, shipboard and airborne). This study should outline approaches to solving attendant problems, so as to ensure the operational suitability and effectiveness of various weapon system designs.

(4) An investigation should be initiated to assess the practicality, suitability, and technical capability of implementing sophisticated fault tolerant/redundant system designs that will be required to achieve space-based Directed Energy System reliability goals.

(5) The ever-increasing cost of computer software necessitates that serious consideration be given to adopting a standard high order language (HOL) and computer instruction set architecture (ISA) for Directed Energy Weapon System embedded processors. These measures, coupled with a structured approach to software development, will reduce software development risks and develop a software base that is transportable between various weapon system applications.

8.2 Weapon Control System

(1) VLSI/VHSIC are expected to have a dramatic impact on the size and performance of future military computer designs. In the interest of ensuring a higher degree of reliability in embedded weapon system processors, it is recommended that computer aided design (CAD) data bases be exploited to develop and demonstrate computer aided test development (CATD) techniques for VLSI/VHSIC.

(2) Technological advances in microelectronics and fiber optics are expected to have an appreciable impact on weapon system architectures of the future. It is within this context that an adaptive data transmission and multiplexing test bed should be developed for use in evaluating data processing configurations; data transmission systems; and interface media, hardware and components which should be standardized for weapon system application.

8.3 Acquisition, Pointing and Tracking

(1) Additional development work is required to improve and demonstrate the performance (sensitivity) and reliability of detector arrays (cooled and uncooled) for acquisition, pointing and tracking functions.

(2) The Development and demonstration of artificial intelligence and VLSI/VHSIC designs to improve the reliability of the target identification, aimpoint selection and aimpoint maintenance functions should be pursued.

8.4 Device

(1) Laser devices have not yet transitioned from the laboratory environment to a weapons system environment. To facilitate this transfer from an R&M point of view a two pronged program is recommended. The first is to provide a critical assessment of device reliability based on laboratory performance, segregating those areas that would benefit from technology advances from those that would benefit primarily from engineering development. The second is to provide the necessary technology or engineering development programs. Examples includes:

a) high voltage/large coulomb spark gap
b) pulse forming network packaging
c) pulsed laser optical component coatings

(2) Current state-of-the-art pulsed power supply technology does not support electric laser deployment in situations where weight and volume are critical. This includes prime power sources, alternators, and capacitor storage energy densities.

(3) Significant benefit could be derived from applying computer aided design and computer aided manufacturing (CAD/CAM) to the development of reliable device subsystems.

(4) The suitability of existing composite materials to reduce weight and volume of directed energy devices should be investigated and demonstrated.

8.5 Optics

(1) Scheduled and unscheduled maintenance currently imposes severe limits on optics subsystem availability. It is recommended,

therefore, that techniques be developed to perform these functions while effectively reducing MTTR. Most technology groups will be required to support this effort, however, the combined effort of the optics, robotics, and artificial intelligence technology groups may provide the high pay-off required to improved overall system RMA.

(2) Improve the reliability of reflective coatings to survive environmental conditions, increase reflectivity and increase pulsed-energy tolerance at shorter wavelengths.

(3) Develop the technologies that provide common beam paths for the HEL beam, the target return beam, and the system alignment beam. This requires:

(a) Multi-wavelength coatings
(b) Shared apertures
(c) High fidelity, low efficiency diffraction beam samplers
(d) Unique and innovative beam sampling techniques other than by diffraction

(4) Develop improved mirror heat exchanger efficiencies to reduce system facility requirements and reduce optical system jitter and improve reliability of mirror coatings by reducing temperatures of coatings.

(5) Develop and demonstrate high-speed active tilt mirror capabilities to $>$1000 Hz.

(6) Develop diagnostic/prognostic techniques to improve reliability and performance of system - especially phase meters.

(7) Develop very light weight, very high strength materials with which to fabricate the ever larger optical apertures and the very high speed active optics.

(8) Develop high-resolution deformable mirrors for short wavelength systems.

(9) Develop polishing technique for short wavelength mirror surfaces.

Although Government funding is presently supporting research and development in a number of these areas, it is important that national priorities be reassessed, and that appropriate funding be made available in those areas requiring additional attention so as to ensure the timely suitability, availability and reliability of future Directed Energy Weapon Systems.

APPENDIX A

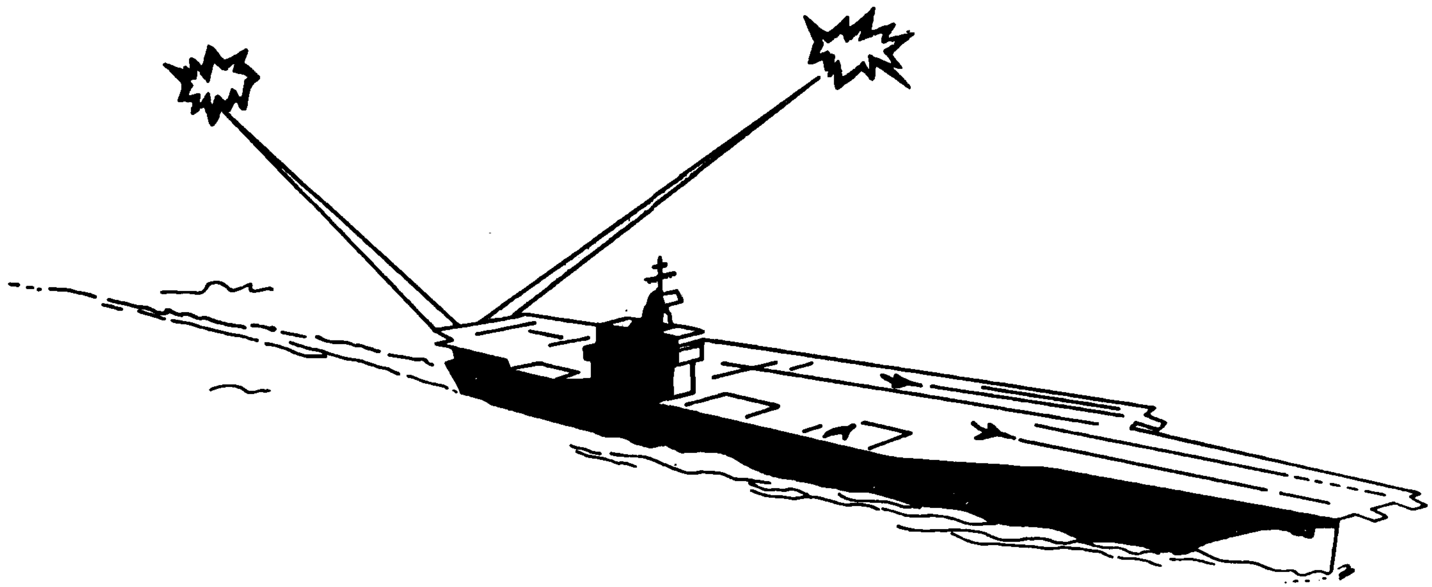
- - CASE STUDY - -

OPEN OCEAN CARRIER TASK FORCE

ANTI-SHIP MISSILE DEFENSE (ASMD)

CASE STUDY

OPEN OCEAN CARRIER TASK FORCE ANTI-SHIP MISSILE DEFENSE (ASMD)



6 APRIL 1983

SPERRY

GK 19 11J4B

FOREWORD

THE SCENARIO, MISSION, AND LASER SYSTEM OPERATIONAL REQUIREMENTS CONTAINED HEREIN HAVE BEEN POSTULATED FOR USE IN PREPARING A MEANINGFUL RELIABILITY, MAINTAINABILITY, AND AVAILABILITY (RMA) MODEL FOR USE IN THIS STUDY

SPERRY

GK 1134 i

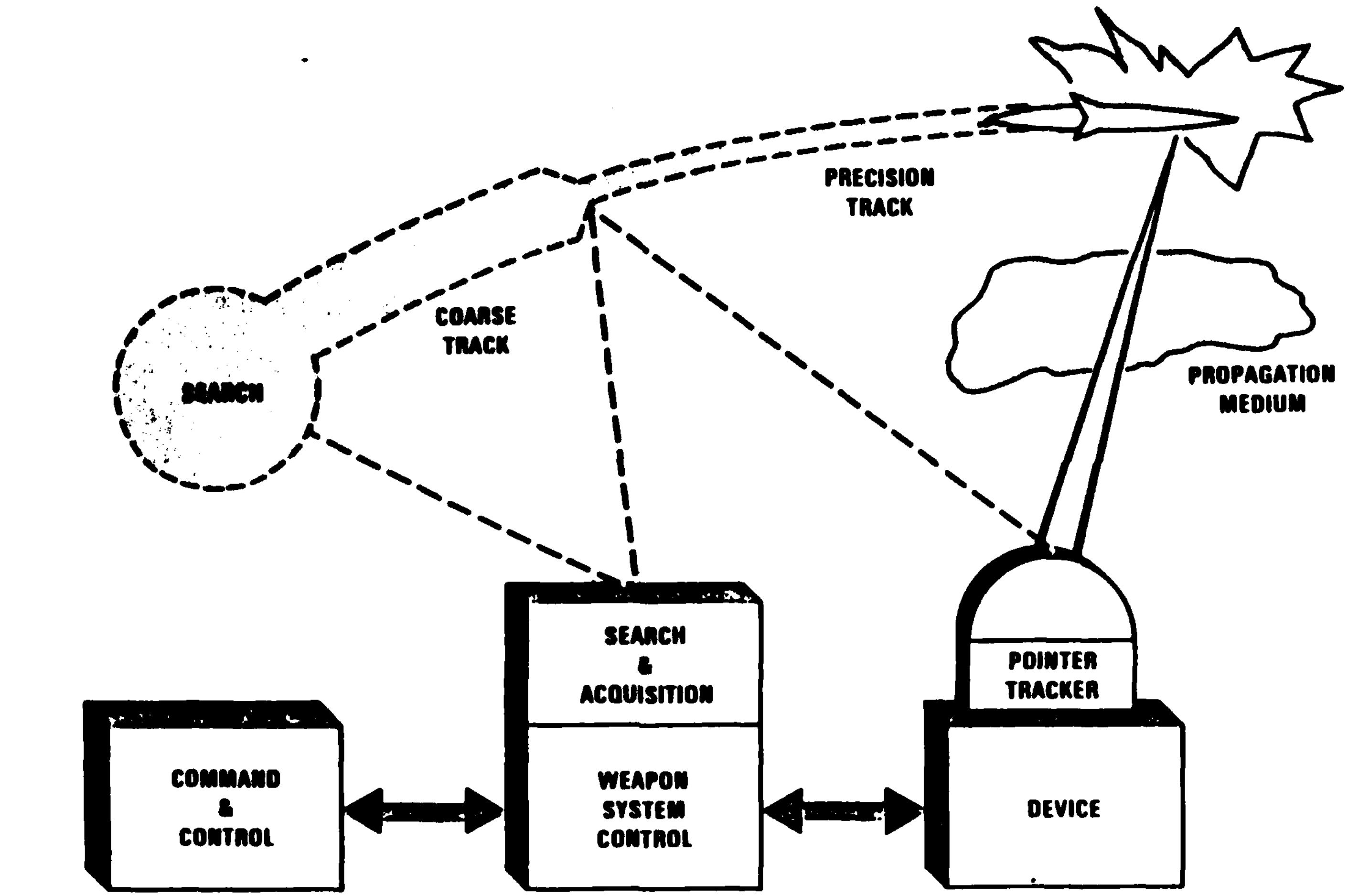
SCENARIO

- OPEN OCEAN, CARRIER TASK FORCE ANTI-SHIP MISSILE DEFENSE (ASMD) SCENARIO
    - MULTIPLE THREAT ENGAGEMENT
        - ENGAGEMENT INTERVAL: UP TO 10 MINUTES
    - OUTER DEFENSE PENETRATION
        - NUMBER OF TARGETS: MAXIMUM OF 10

SPERRY

GK-1134-1

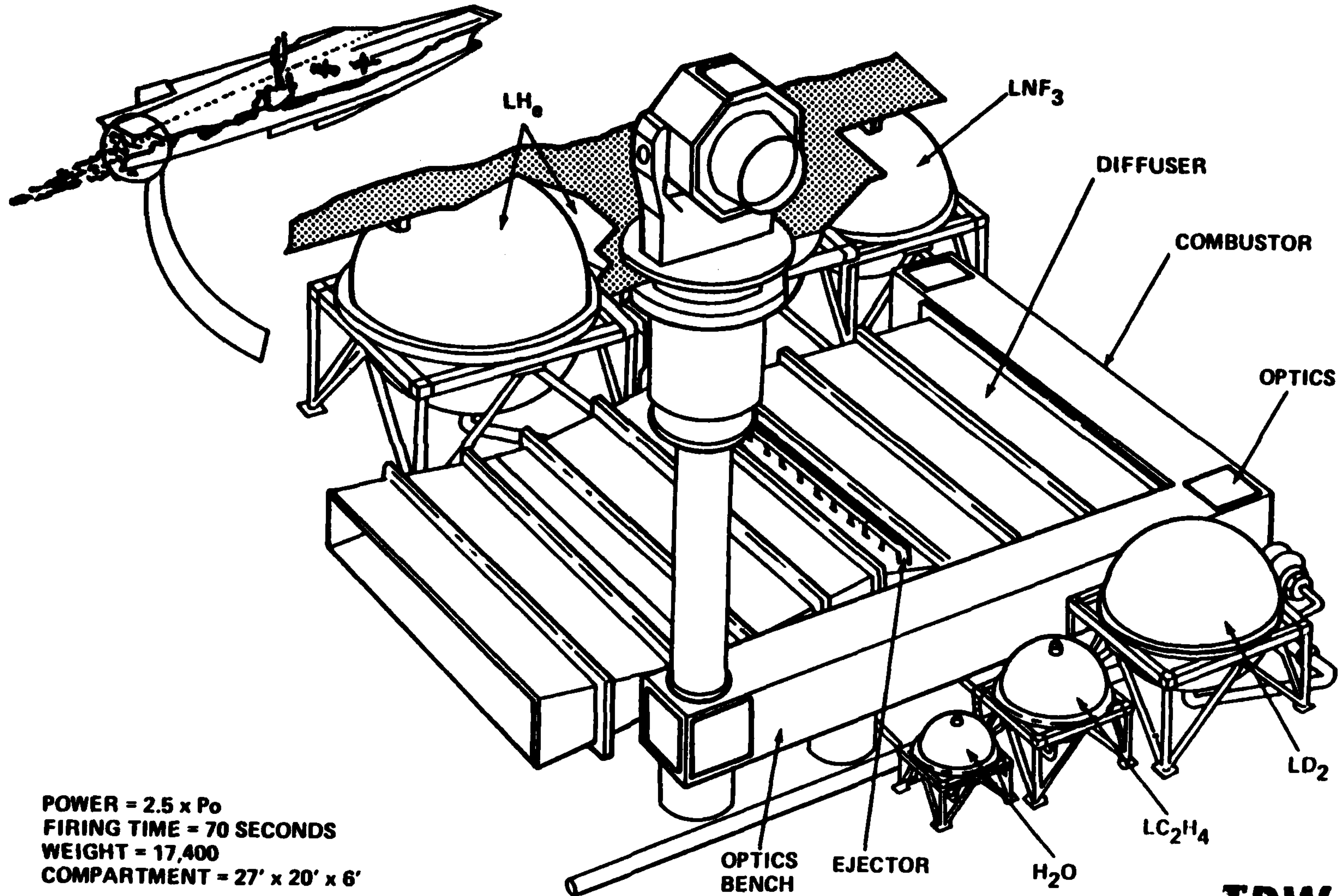
DIRECTED ENERGY WEAPON SYSTEM
(KEY ELEMENTS)



SPERRY

GK 1134 2

SHIPBOARD LASER SYSTEM



POWER = 2.5 x Po
FIRING TIME = 70 SECONDS
WEIGHT = 17,400
COMPARTMENT = 27' x 20' x 6'

TRW
DEFENSE AND SPACE SYSTEMS GROUP

GK-1134.3

MISSION

- CLOSE-IN WEAPON SYSTEM SUPPORT
  - ACQUIRE, TRACK, ENGAGE, AND KILL AIR, SURFACE, AND SUB-SURFACE LAUNCHED MISSILES AT RANGES IN EXCESS OF 6 NAUTICAL MILES (NM)
    - SELF-DEFENSE FOR HIGH-VALUE UNITS (E.G., CARRIERS, FAST COMBAT SUPPORT SHIPS, ETC.)
    - SUPPORT DEFENSE FOR TASK FORCE

SPERRY

GK 1134-4

THREAT PENETRATION

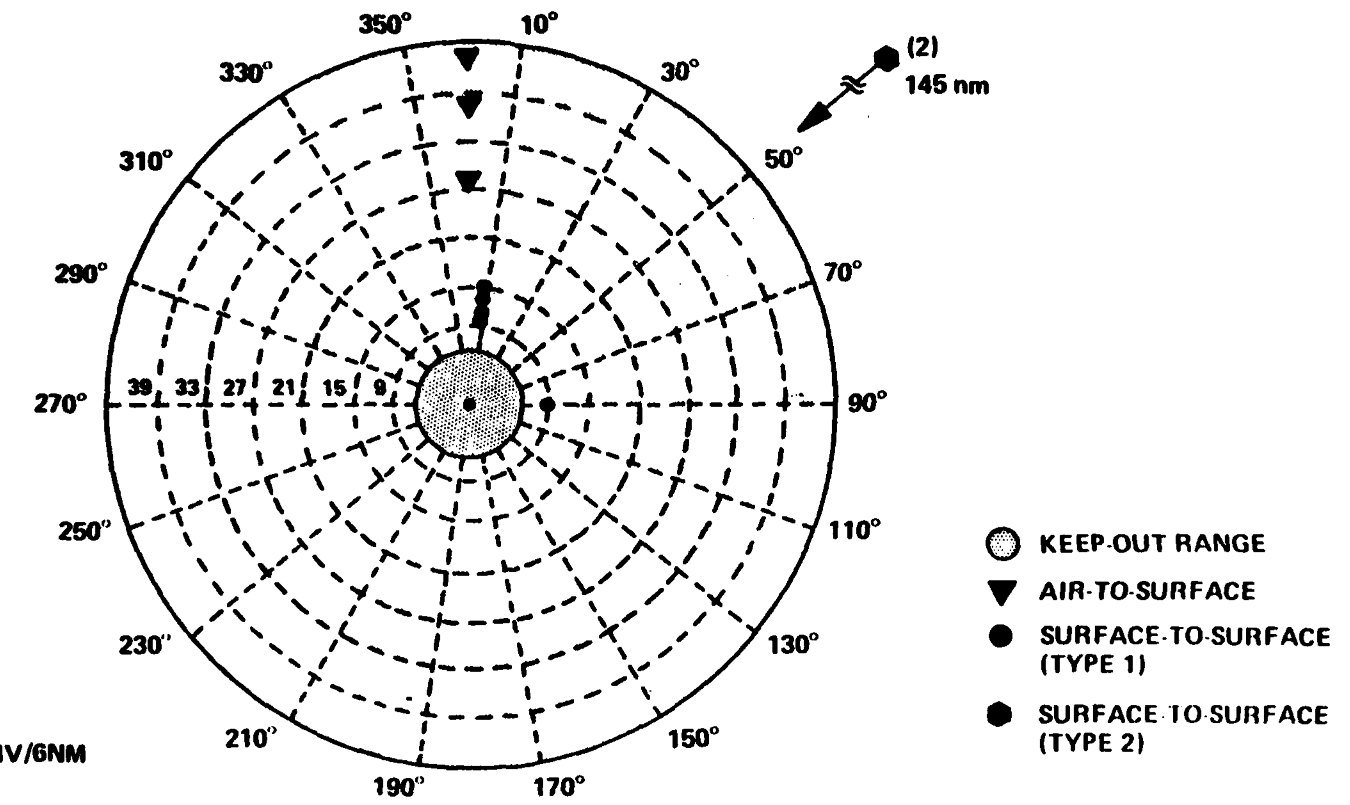
STREAM NUMBER	THREAT TYPE	BEARING (Brg) (DEGREES TRUE)	LAUNCH TIME (SEC.)	LAUNCH RANGE (NM)	ARRIVAL TIME (SEC.)
1	AIR-TO-SURFACE	0	0 20 30	170	356 376 386
2	SURFACE-TO-SURFACE (TYPE 1)	10	120 130 140 145	37	379 389 399 404
3	SURFACE-TO-SURFACE (TYPE 2)	50	0 0	237	770 770
4	SURFACE-TO-SURFACE (TYPE 1)	90	130	34	368

SPERRY

GK-1134-5

ENGAGEMENT GEOMETRY

(SNAPSHOT AT t_0 +300 SECONDS)



SCALE: 1 DIV/6NM

SPERRY

GK 1131-6

OPERATIONAL REQUIREMENTS

- MAXIMUM ACQUISITION RANGE: 12.5
- MAXIMUM ACQUISITION AND TRACK INTERVAL: 5 SEC.
- MAXIMUM KILL TIME (BURN TIME): 5 SEC.
- MAXIMUM LASER RUN TIME: 70 SEC.

SPERRY

GK-1134 7

OPERATIONAL CONSTRAINTS

- METEOROLOGICAL CONDITIONS
- EMI, RFI, AND EMP
- COUNTERMEASURES

SPERRY

GK 1134-8

ENGAGE SEQUENCE

ENGAGEMENT TIME (SEC)	STREAM NUMBER	THREAT TYPE	RANGE (NM)	ARRIVAL TIME (SEC.)	TIME TO ACQUIRE (SEC.)	TIME TO ENGAGE (SEC.)	TIME TO KILL (SEC.)	TIME TO KOR (SEC.)
$t_o + 300$	4	S/S (TYPE 1)	9.7	68	−19.61	−14.61	−9.61	25.91
	2	S/S (TYPE 1)	11.3	79	−8.40	−3.40	1.60	37.11
	2	S/S (TYPE 1)	12.7	89	1.60	6.60	11.60	46.92
	2	S/S (TYPE 1)	14.1	99	11.60	16.60	21.60	56.72
	1	A/S	26.8	56	29.91	34.91	39.91	43.51
	2	S/S (TYPE 1)	14.9	104	39.91	44.91	49.91	62.32
	1	A/S	36.3	76	49.91	54.91	59.91	63.39
	1	A/S	41.1	86	59.91	64.91	69.91	73.43
	3	S/S (TYPE 2)	144.7	470	429.22	434.22	439.22	450.32
	3	S/S (TYPE 2)	144.7	470	439.22	444.22	449.22	450.32

SPERRY

GK-1134 9

READINESS CONDITIONS

- READINESS CONDITION III
  - WEAPON SYSTEM IS MANNED AND CAPABLE OF DEFENDING THE SHIP
    - ROUTINE UNDERWAY MAINTENANCE AND REPAIR IS PERMITTED
  - MAXIMUM CREW ENDURANCE IS 60 DAYS
- READINESS CONDITION I
  - WEAPON SYSTEM IS FULLY MANNED AND READY TO SUPPORT AN ENGAGEMENT
    - ONLY EMERGENCY REPAIR PERMITTED
  - MAXIMUM CREW ENDURANCE IS 24 HOURS

SPERRY

GK 1134 10

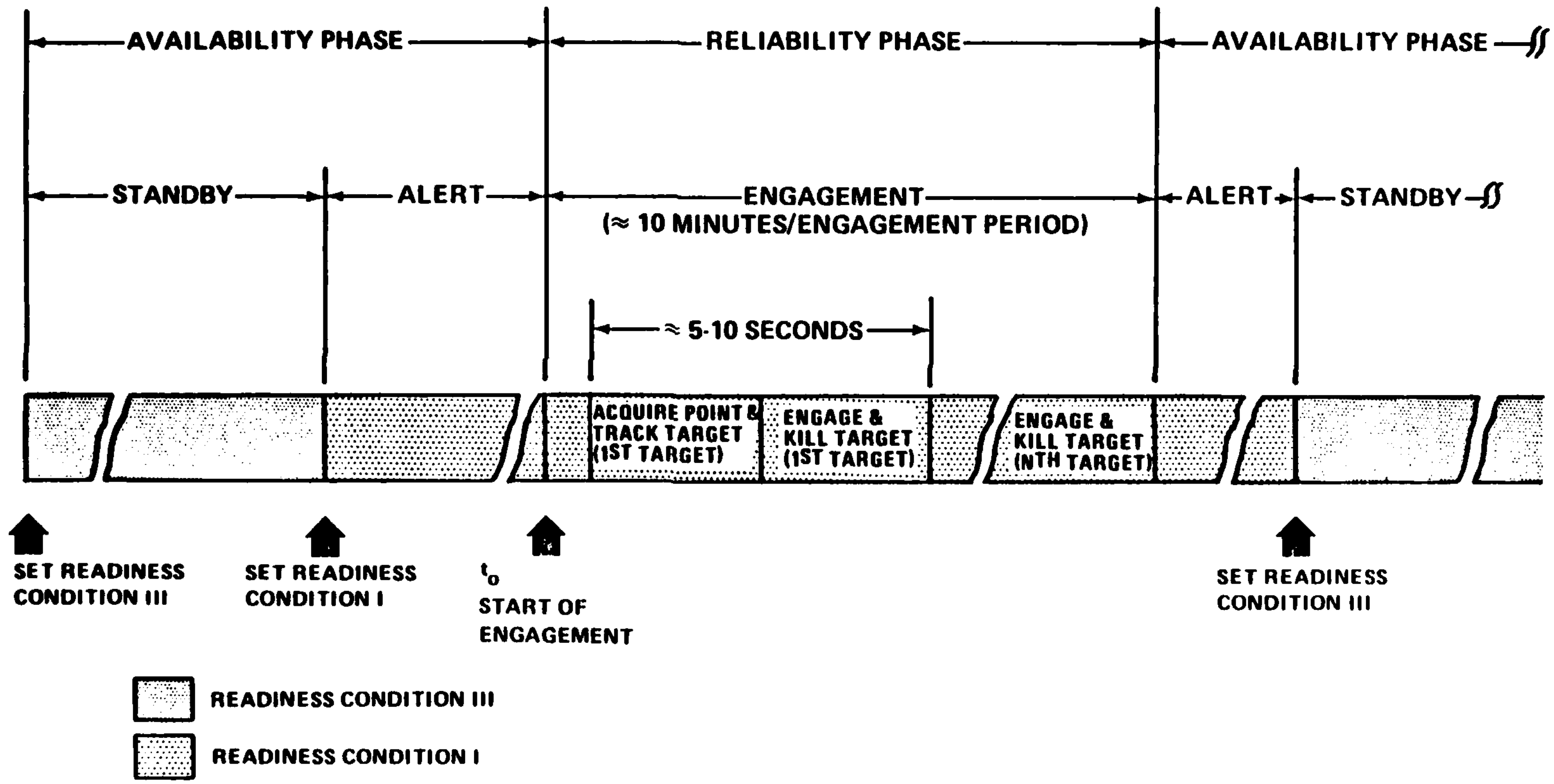
READINESS PHASES

- AVAILABILITY PHASE
  - ENCOMPASSES READINESS CONDITIONS III AND I
    - MAINTENANCE AND REPAIR ACTIONS PERMITTED WITHIN SPECIFIED LIMITS
- RELIABILITY PHASE
  - OCCURS WITHIN READINESS CONDITION I
    - SYSTEM FAILURES MAY NOT BE TOLERATED

SPERRY

GK 1134 11

RMA MODEL



SPERRY

GK 1134 12

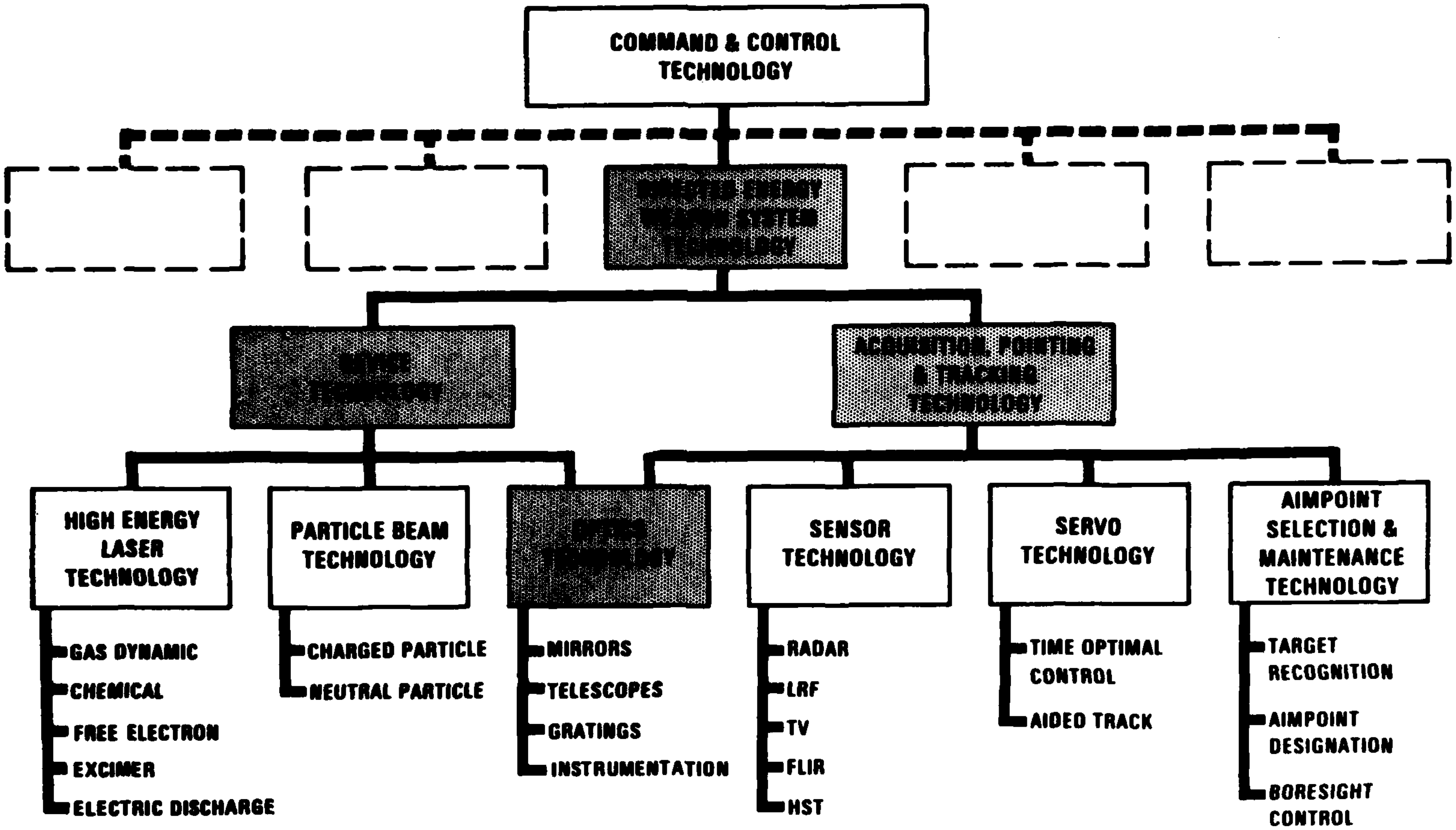
TASK FORCE EFFECTIVENESS

- OVERALL PROBABILITY OF PENETRATING HIGH-VALUE UNIT SUPPORT DEFENSE IS 0.10
- SINGLE ENGAGEMENT PROBABILITY OF SUCCESS (LASER KILL) IS 0.95

SPERRY

GK-1134-13

DIRECTED ENERGY WEAPON SYSTEMS TECHNOLOGY



SPERRY

GK-1134-14

SUBSYSTEM RMA ALLOCATION PROCESS

SINGLE ENGAGEMENT PROBABILITY OF SUCCESS (P_S)

$$P_{(SYSTEM)} = \left[P_{(ACQ,\ P/T)}\right]_1 \left[P_{(WPN\ CONT)}\right]_2 \left[P_{(DEV)}\right]_3 \left[P_{OPT}\right]_4$$

OR

$$P_{(SYSTEM)} = \prod_{i=1}^{i=4} A_i \cdot R_i$$

$$\text{WHERE: } A_i = \left[\frac{MTBF_i}{MTBF_i + MTTR_i}\right]$$

$$R_i = \left[e^{-T/MTBF_i}\right]$$

<u>NOTE:</u> A_i = STEADY STATE AVAILABILITY PHASE
R_i = RELIABILITY PHASE
T = ENGAGEMENT INTERVAL

SPERRY

GK-1134-15

BASIS FOR INITIAL RMA ALLOCATION

- MTTR AND MTBF ALLOCATIONS WERE DEFINED BASED ON ASSESSMENTS OF THE PRESENT STATE-OF-THE-ART
  - MTTR CRITERIA
    - SUBSYSTEM COMPLEXITY
    - LIKELIHOOD OF EQUIPMENT FAILURE
    - MAINTENANCE ACCESS
  - MTBF CRITERIA
    - RELATIVE SUBSYSTEM COMPLEXITY
    - NATURE OF EQUIPMENT AND ENVIRONMENT

SPERRY

GK 1134 16

BASIS FOR INITIAL ALLOCATION (CONT)

- THE RESULTANT RELATIONSHIPS THAT WERE USED TO DEVELOP THE INITIAL ALLOCATIONS ARE SHOWN BELOW

SUBSYSTEM	MTTR (HOURS)	RELATIVE MTBF
ACQUISITION, POINTING, AND TRACKING	4	1
WEAPON CONTROL	1	40
DEVICE	10	2
OPTICS	10	10

SPERRY

GK 1134 17

SYSTEM RMA ALLOCATION SUMMARY

SINGLE ENGAGEMENT PROBABILITY OF SUCCESS (P)				RMA ALLOCATION	
				MTBF (HOURS)	MTTR (HOURS)
SYSTEM	0.95	WEAPON CONTROL	0.9998	8000	1
		DEVICE	0.9750	400	10
		OPTICS	0.9949	2000	10
		ACQUISITION, POINTING & TRACKING	0.9792	200	4

SPERRY

GK 1134-18

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: WEAPON CONTROL

MTBF: 8000 HOURS

MTTR: 1 HOUR

MAJOR SUBSYSTEM FUNCTIONAL GROUP	DESCRIPTION	RMA ALLOCATION	
		MTBF	MTTR
RESOURCE MANAGEMENT	• SYSTEM CONFIGURATION • READINESS VERIFICATION • CONSUMABLES INVENTORY		
SYSTEM SEQUENCING	• COMMUNICATIONS • THREAT ASSESSMENT • ENCASEMENT SEQUENCE • SYSTEM CONTROL • KILL ASSESSMENT		
SAFETY & SURVEILLANCE	• HEALTH MONITORING • CONTINGENCY ASSESSMENT • SYSTEM ABORT & SHUTDOWN		

SPERRY

GK-1134-19A

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: DEVICE	MTBF: 400 HOURS	MTTR: 10 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	RMA ALLOCATION	
	MTBF	MTTR
POWER SUPPLIES		
FLUID SUPPLIES		
GAIN MEDIUM GENERATION		
EXHAUST MANAGEMENT		
INSTRUMENTATION, CONTROLS & DISPLAYS		

SPERRY

GK-1134-19B

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: OPTICS

MTBF: 2000 HOURS

MTTR: 10 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	DESCRIPTION	RMA ALLOCATION	
		MTBF	MTTR
BEAM GENERATION	• FEEDBACK • MAGNIFICATION • SCRAPING • MEDIA INTERFACE		
BEAM MANAGEMENT & CONTROL	• SUBSYSTEM CONTROL • HEALTH MONITORING • SHAPING • WAVEFRONT MANAGEMENT • STEERING • SIZING • STATIC, AUXILIARY BEAM & MAIN BEAM ALIGNMENT		
BEAM DELIVERY	• TURNING • SAMPLING • MEDIA INTERFACE • ENERGY SENSING		

SPERRY

GK-1134-19C

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: ACQ. P & T

MTBF: 200 HOURS

MTTR: 4 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	DESCRIPTION	RMA ALLOCATION	
		MTBF	MTTR
CONTROL & BORESIGHT SELECTION	• SUBSYSTEM CONTROL • HEALTH MONITORING • TARGET TRACKING • TARGET RECOGNITION		
BORESIGHT ESTABLISHMENT	• STATIC ALIGNMENT • AIMPOINT DESIGNATION		
BORESIGHT MAINTENANCE	• AIMPOINT MAINTENANCE • AUXILIARY BEAM ALIGNMENT		
BORESIGHT CORRECTION	• MAIN BEAM ALIGNMENT • BIAS COMPENSATION		

SPERRY

GK-1134-19D

SUBSYSTEM RMA ASSESSMENT

SUBSYSTEM:	MTBF: HOURS	MTTR: HOURS

MAJOR SUBSYSTEM FUNCTION	MTBF		MTTR	
	ALLOCATED	EXISTING	ALLOCATED	EXISTING

SPERRY

GK-1134-20

TECHNOLOGY MATRIX (PRELIM)

DIRECTED ENERGY WEAPON SYSTEM	NEW SUPPORT TECHNOLOGIES														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
WEAPON CONTROL	X	X	X	X			X	X	X						
DEVICE		X	X	X		X	X	X	X	X	X	X	X	X	
OPTICS		X		X		X	X		X	X		X		X	
ACQUISITION, POINTING, & TRACKING	X	X	X	X		X	X	X	X	X	X	X	X	X	

1 – VERY HIGH SPEED INTEGRATED CIRCUITS (VHSIC)
2 – TESTING TECHNOLOGY
3 – OPERATIONAL SOFTWARE
4 – MANPOWER AND TRAINING
5 – ARTIFICIAL INTELLIGENCE
6 – NON-DESTRUCTIVE TESTING
7 – CABLING/CONNECTORS
8 – FIBER OPTICS
9 – PACKAGING & INTERCONNECT MODULES
10 – MECHANICAL SYSTEMS CONDITION MONITOR
11 – POWER SUPPLIES
12 – DIAGNOSTICS
13 – COMPUTER AIDED DESIGN/ MANUFACTURING (CAD/CAM)
14 – COMPOSITE MATERIALS
15 – ROBOTICS

SPERRY

GK-1134-21

RMA IMPROVEMENT

SUBSYSTEM:

MAJOR SUBSYSTEM FUNCTION:

APPLICABLE TECHNOLOGY	DESCRIPTION OF IMPROVEMENT	PREDICTED IMPROVEMENT	
		MTBF (HOURS)	MTTR (HOURS)

SPERRY

GK 1134 22

APPENDIX B

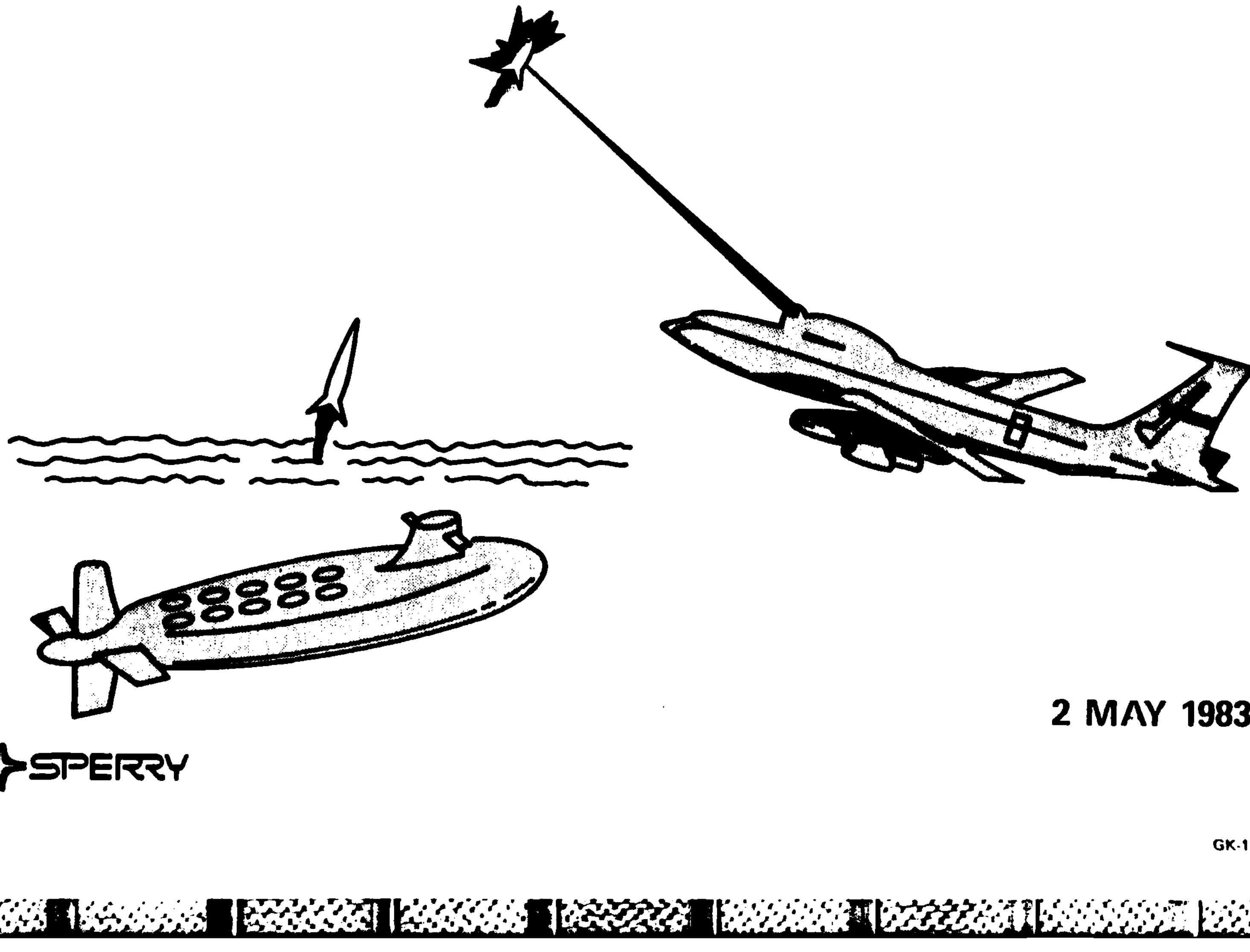
- - CASE STUDY - -

AIRBORNE SEA-LAUNCHED BALLISTIC MISSILE

(SLBM) DEFENSE

CASE STUDY

AIRBORNE SEA-LAUNCHED BALLISTIC MISSILE (SLBM) DEFENSE



2 MAY 1983

SPERRY

GK-19-1137

FOREWORD

THE SCENARIO, MISSION, AND LASER SYSTEM OPERATIONAL REQUIREMENTS CONTAINED HEREIN HAVE BEEN POSTULATED FOR USE IN PREPARING A MEANINGFUL RELIABILITY, MAINTAINABILITY, AND AVAILABILITY (RMA) MODEL FOR USE IN THIS STUDY

SPERRY

GK 11371

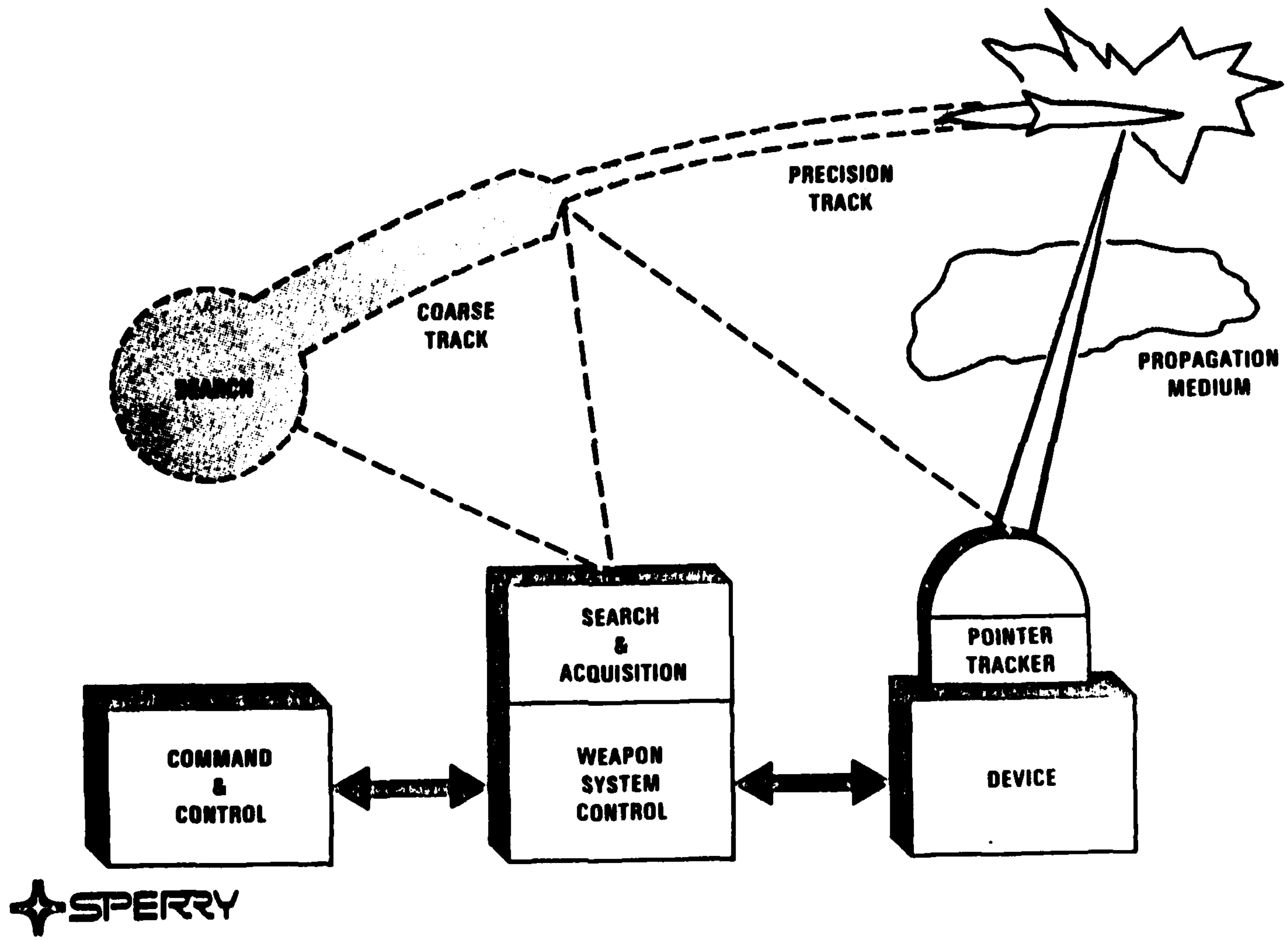
SCENARIO

- AIRBORNE SEA-LAUNCHED BALLISTIC MISSILE (SLBM) DEFENSE SCENARIO
    - MULTIPLE THREAT ENGAGEMENT
        - ENGAGEMENT INTERVAL: UP TO 10 MINUTES
        - NUMBER OF TARGETS: MAXIMUM OF 10

SPERRY

GK-1137 2

DIRECTED ENERGY WEAPON SYSTEM (KEY ELEMENTS)



GK-1137 3

MISSION

- OUTER ZONE GLOBAL BALLISTIC MISSILE DEFENSE (GBMD) FOR THE CONTINENTAL UNITED STATES
  - ACQUIRE, TRACK, ENGAGE AND KILL SLBMs DURING THE EARLY (BOOST) PHASE OF FLIGHT
    - AIRCRAFT OPERATING ALTITUDE: 35,000 FEET
    - ENGAGE AND KILL BETWEEN 20,000 AND 40,000 FEET

SPERRY

GK-1137 4

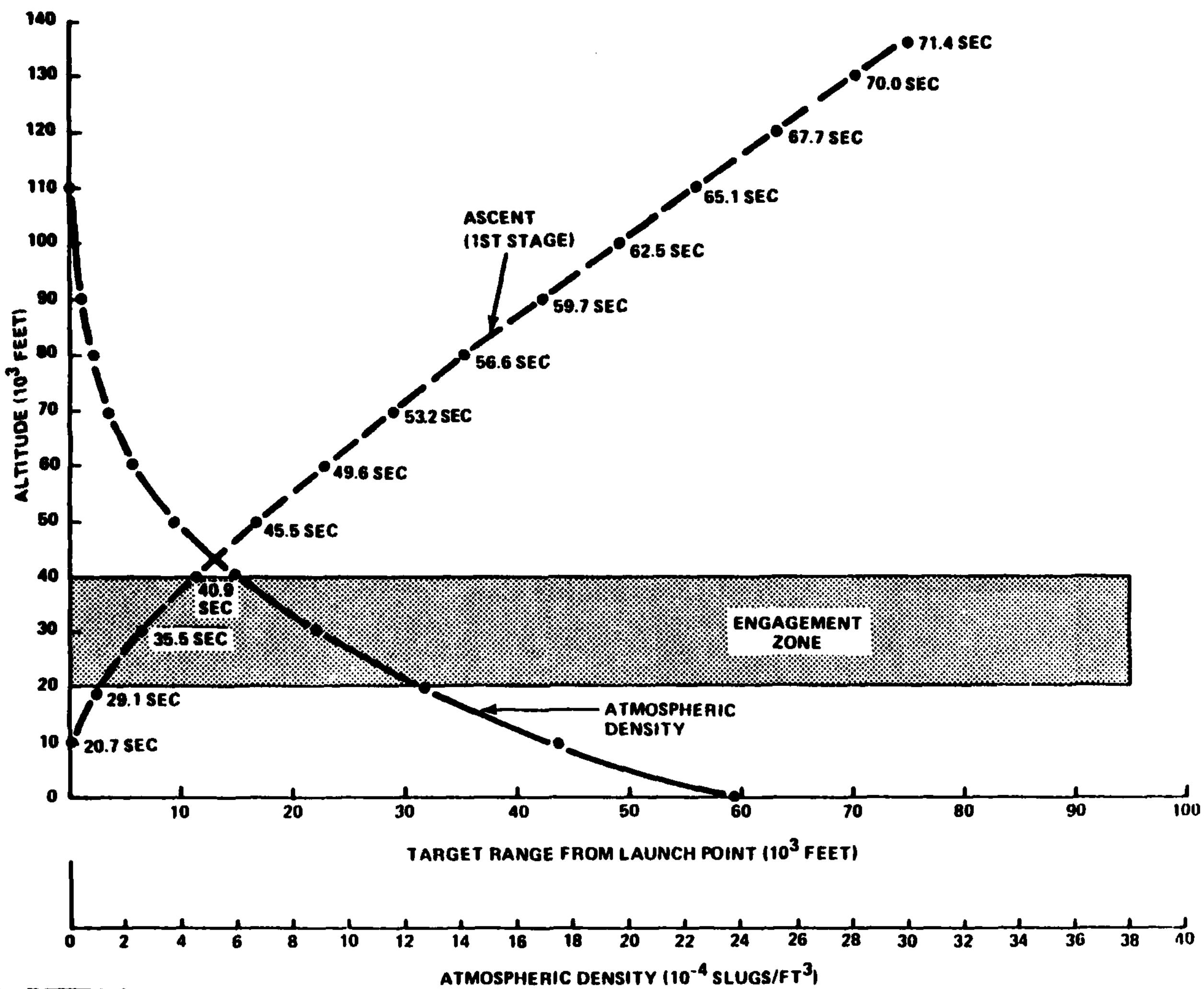
THREAT

MISSILE	THREAT TYPE	LAUNCH TRAJECTORY (DEGREES)	LAUNCH TIME (SEC)	LAUNCH RANGE (NM)	TIME TO KOR (SEC)
1	SLBM	45	0	30.0	41
2	SLBM	45	15	27.5	56
3	SLBM	45	30	25.0	71
4	SLBM	45	45	22.5	86
5	SLBM	45	60	20.0	101
6	SLBM	45	75	17.5	116
7	SLBM	45	90	15.0	131
8	SLBM	45	105	12.5	146
9	SLBM	45	120	10.0	161
10	SLBM	45	135	7.5	176

SPERRY

GK-1137-5

TYPICAL TARGET TRAJECTORY PROFILE



SPERRY

GK-1137 6

OPERATIONAL REQUIREMENTS

- MAXIMUM ACQUISITION RANGE: 25 NM
- MAXIMUM ACQUISITION AND TRACK INTERVAL: 5 SEC.
- MAXIMUM KILL TIME (BURN TIME): 5 SEC.
- MAXIMUM LASER RUN TIME: 70 SEC.

SPERRY

GK 1137 7

OPERATIONAL CONSTRAINTS

- METEOROLOGICAL CONDITIONS
- COUNTERMEASURES

SPERRY

GK-1137-8

ENGAGE SEQUENCE

ENGAGEMENT TIME (SEC)	MISSILE	THREAT TYPE	TIME TO ACQUIRE (SEC)	TIME TO ENGAGE (SEC)	TIME TO KILL (SEC)	TIME TO KOR (SEC)
t_o	1	SLBM	30	35	40	41
	2	SLBM	40	45	50	56
	3	SLBM	50	60	65	71
	4	SLBM	65	75	80	86
	5	SLBM	80	90	95	101
	6	SLBM	95	105	110	116
	7	SLBM	110	120	125	131
	8	SLBM	125	135	140	146
	9	SLBM	140	150	155	161
	10	SLBM	155	165	170	176

SPERRY

GK-1137 9

READINESS CONDITIONS

- READINESS CONDITION II
    - AIRCRAFT AND WEAPON SYSTEM IN STANDBY AND CAPABLE OF BEING AIRBORNE IN 15 MINUTES
        - ROUTINE MAINTENANCE AND REPAIR IS PERMITTED
    - MAXIMUM CREW ENDURANCE IS 24 HOURS
- READINESS CONDITION I
    - AIRCRAFT IS AIRBORNE AND WEAPON SYSTEM IS MANNED AND CAPABLE OF SUPPORTING AN ENGAGEMENT
        - SYSTEM FAILURES MAY NOT BE TOLERATED
    - MAXIMUM CREW ENDURANCE IS 6 HOURS

SPERRY

GK 1137 10

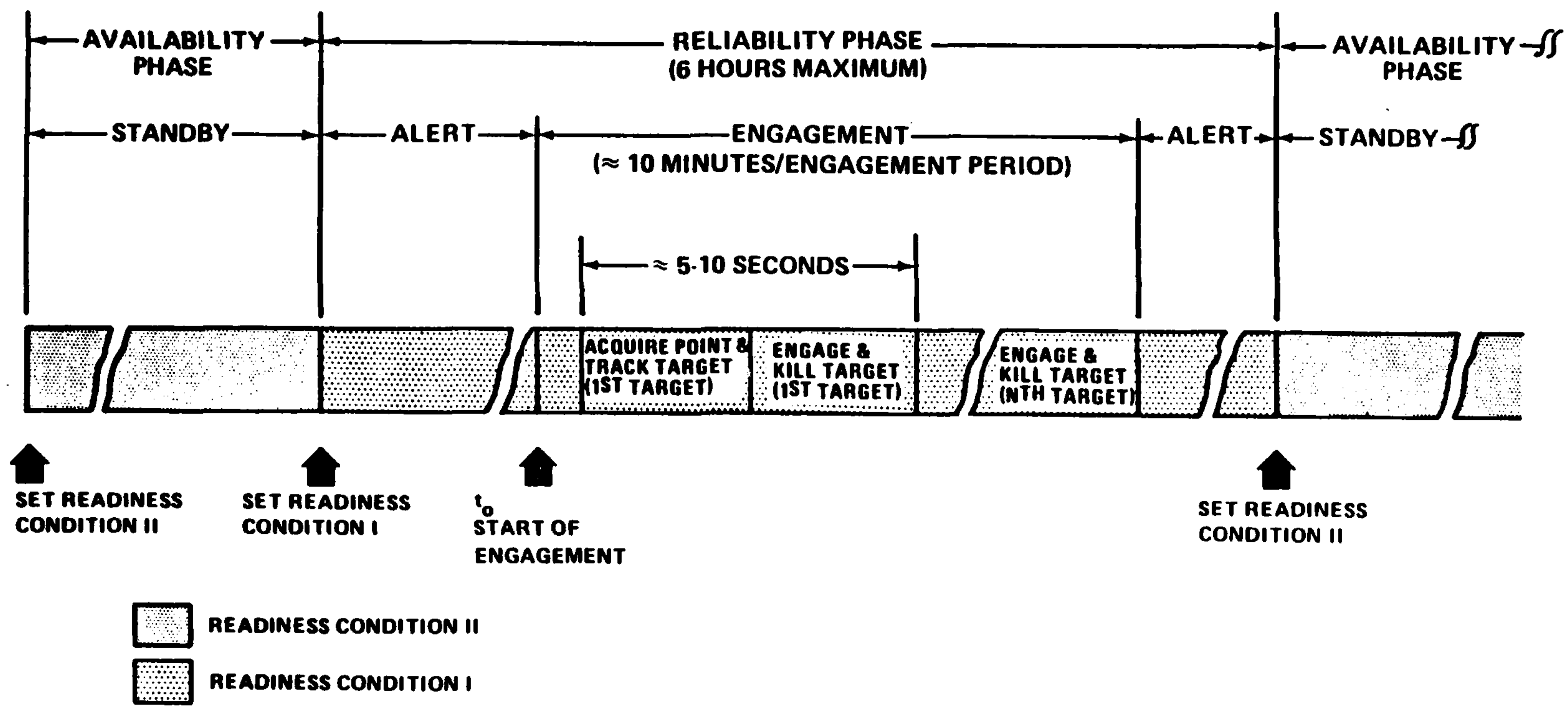
READINESS PHASES

- AVAILABILITY PHASE
  - ENCOMPASSES READINESS CONDITIONS II AND I
    - MAINTENANCE AND REPAIR ACTIONS PERMITTED WITHIN SPECIFIED LIMITS
- RELIABILITY PHASE
  - OCCURS WITHIN READINESS CONDITION I
    - SYSTEM FAILURES MAY NOT BE TOLERATED

SPERRY

GK 1137-11

RMA MODEL



SPERRY

GK-1137 12

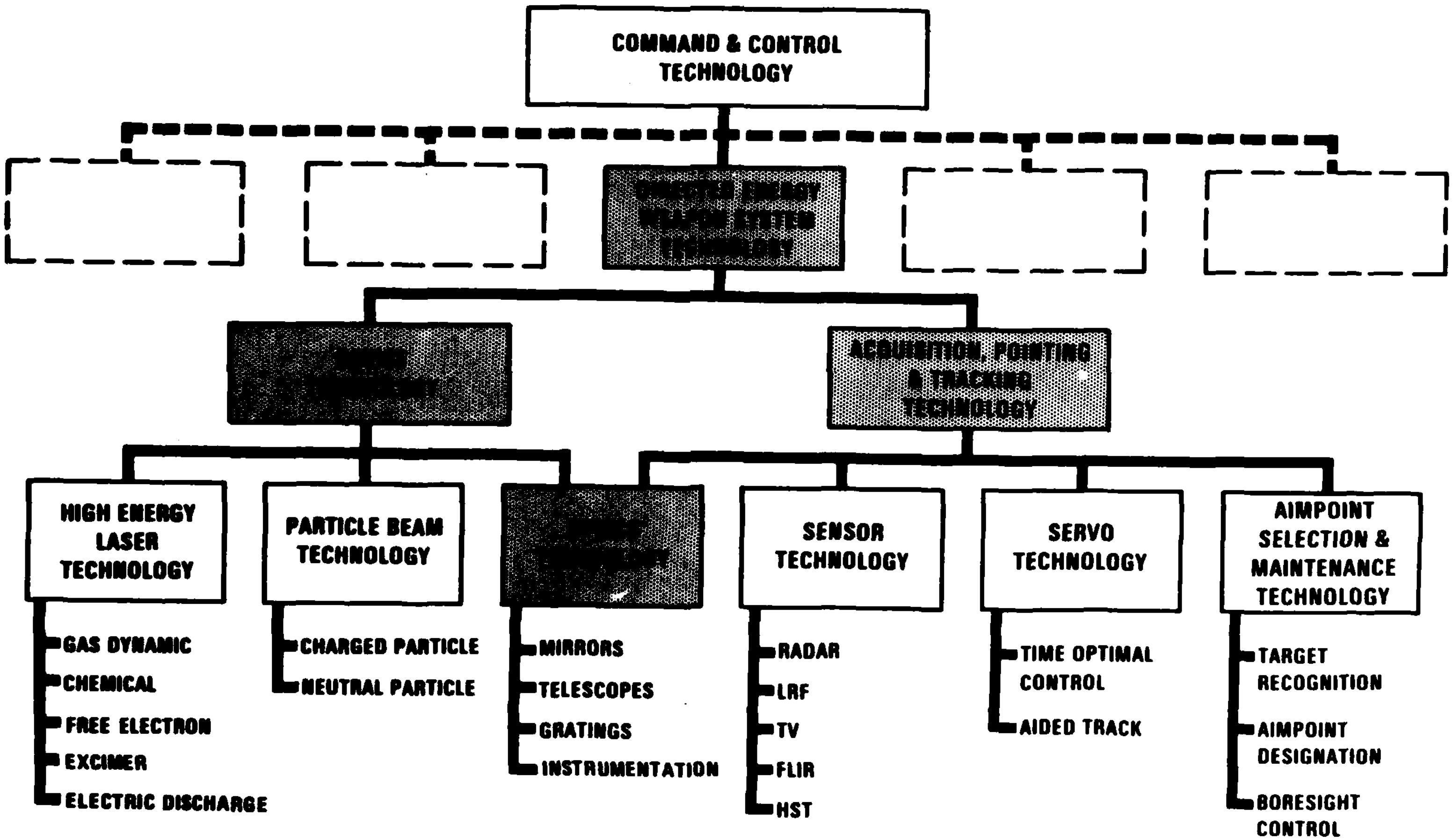
GBMD SYSTEM EFFECTIVENESS

- GLOBAL BALLISTIC MISSILE DEFENSE (GBMD) SYSTEM IS CAPABLE OF SUPPORTING THREE PHASES OF ENGAGEMENT
    - EARLY (BOOST) ENGAGEMENT PHASE
        - SINGLE ENGAGEMENT PROBABILITY OF SUCCESS (LASER KILL) IS 0.80
    - MID ENGAGEMENT PHASE
        - SINGLE ENGAGEMENT PROBABILITY OF SUCCESS IS 0.80
    - TERMINAL ENGAGEMENT PHASE
        - SINGLE ENGAGEMENT PROBABILITY OF SUCCESS IS 0.95

SPERRY

GK 1137-13

DIRECTED ENERGY WEAPON SYSTEMS TECHNOLOGY



SPERRY

GK-1137-14

SUBSYSTEM RMA ALLOCATION PROCESS

SINGLE ENGAGEMENT PROBABILITY OF SUCCESS (P_S)

$$P_{(SYSTEM)} = \left[P_{(ACQ,\ P/T)}\right]_1 \left[P_{(WPN\ CONT)}\right]_2 \left[P_{(DEV)}\right]_3 \left[P_{OPT}\right]_4$$

OR

$$P_{(SYSTEM)} = \prod_{i=1}^{i=4} A_i \cdot R_i$$

$$\text{WHERE: } A_i = \left[\frac{MTBF_i}{MTBF_i + MTTR_i}\right]$$

$$R_i = \left[e^{-T/MTBF_i}\right]$$

NOTE: A_i = STEADY STATE AVAILABILITY PHASE
R_i = RELIABILITY PHASE
T = READINESS CONDITION 1 INTERVAL (6 HOURS MAXIMUM)

SPERRY

GK 1137-15

BASIS FOR INITIAL RMA ALLOCATION

- MTTR AND MTBF ALLOCATIONS WERE DEFINED BASED ON ASSESSMENTS OF THE PRESENT STATE-OF-THE-ART
    - MTTR CRITERIA
        - SUBSYSTEM COMPLEXITY
        - LIKELIHOOD OF EQUIPMENT FAILURE
        - MAINTENANCE ACCESS
    - MTBF CRITERIA
        - RELATIVE SUBSYSTEM COMPLEXITY
        - NATURE OF EQUIPMENT AND ENVIRONMENT

SPERRY

GK-113716

BASIS FOR INITIAL ALLOCATION (CONT)

- THE RESULTANT RELATIONSHIPS THAT WERE USED TO DEVELOP THE INITIAL ALLOCATIONS ARE SHOWN BELOW

SUBSYSTEM	MTTR (HOURS)	RELATIVE MTBF
ACQUISITION, POINTING, AND TRACKING	8	1
WEAPON CONTROL	2	40
DEVICE	20	2
OPTICS	20	10

SPERRY

GK-1137-17

SYSTEM RMA ALLOCATION SUMMARY

SINGLE ENGAGEMENT PROBABILITY OF SUCCESS (P)				RMA ALLOCATION	
				MTBF (HOURS)	MTTR (HOURS)
SYSTEM	0.80	WEAPON CONTROL	0.9985	5200	2
		DEVICE	0.9074	260	20
		OPTICS	0.9803	1300	20
		ACQUISITION, POINTING & TRACKING	0.8995	130	8

SPERRY

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: WEAPON CONTROL | MTBF: 5200 HOURS | MTTR: 2 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	DESCRIPTION	RMA ALLOCATION	
		MTBF	MTTR
RESOURCE MANAGEMENT	• SYSTEM CONFIGURATION • READINESS VERIFICATION • CONSUMABLES INVENTORY		
SYSTEM SEQUENCING	• COMMUNICATIONS • THREAT ASSESSMENT • ENCASEMENT SEQUENCE • SYSTEM CONTROL • KILL ASSESSMENT		
SAFETY & SURVEILLANCE	• HEALTH MONITORING • CONTINGENCY ASSESSMENT • SYSTEM ABORT & SHUTDOWN		

SPERRY

GK 11.37 19A

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: DEVICE	MTBF: 260 HOURS	MTTR: 20 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	RMA ALLOCATION	
	MTBF	MTTR
POWER SUPPLIES		
FLUID SUPPLIES		
GAIN MEDIUM GENERATION		
EXHAUST MANAGEMENT		
INSTRUMENTATION, CONTROLS & DISPLAYS		

SPERRY

GK-1137-19B

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: OPTICS | **MTBF: 1300 HOURS** | **MTTR: 20 HOURS**

MAJOR SUBSYSTEM FUNCTIONAL GROUP	DESCRIPTION	RMA ALLOCATION	
		MTBF	MTTR
BEAM GENERATION	• FEEDBACK • MAGNIFICATION • SCRAPING • MEDIA INTERFACE		
BEAM MANAGEMENT & CONTROL	• SUBSYSTEM CONTROL • HEALTH MONITORING • SHAPING • WAVEFRONT MANAGEMENT • STEERING • SIZING • STATIC, AUXILIARY BEAM & MAIN BEAM ALIGNMENT		
BEAM DELIVERY	• TURNING • SAMPLING • MEDIA INTERFACE • ENERGY SENSING		

SPERRY

GK 1137-19C

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: ACQ. P & T

MTBF: 130 HOURS

MTTR: 8 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	DESCRIPTION	RMA ALLOCATION	
		MTBF	MTTR
CONTROL & BORESIGHT SELECTION	• SUBSYSTEM CONTROL • HEALTH MONITORING • TARGET TRACKING • TARGET RECOGNITION		
BORESIGHT ESTABLISHMENT	• STATIC ALIGNMENT • AIMPOINT DESIGNATION		
BORESIGHT MAINTENANCE	• AIMPOINT MAINTENANCE • AUXILIARY BEAM ALIGNMENT		
BORESIGHT CORRECTION	• MAIN BEAM ALIGNMENT • BIAS COMPENSATION		

SPERRY

GK-1137 19D

SUBSYSTEM RMA ASSESSMENT

SUBSYSTEM:	MTBF: HOURS	MTTR: HOURS

MAJOR SUBSYSTEM FUNCTION	MTBF		MTTR	
	ALLOCATED	EXISTING	ALLOCATED	EXISTING

SPERRY

GK-1137-20

TECHNOLOGY MATRIX (PRELIM)

DIRECTED ENERGY WEAPON SYSTEM	NEW SUPPORT TECHNOLOGIES														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
WEAPON CONTROL	X	X	X	X			X	X	X						
DEVICE		X	X	X		X	X	X	X	X	X	X	X	X	
OPTICS		X		X		X	X		X	X		X		X	
ACQUISITION, POINTING, & TRACKING	X	X	X	X		X	X	X	X	X	X	X	X	X	

1 – VERY HIGH SPEED INTEGRATED CIRCUITS (VHSIC)
2 – TESTING TECHNOLOGY
3 – OPERATIONAL SOFTWARE
4 – MANPOWER AND TRAINING
5 – ARTIFICIAL INTELLIGENCE
6 – NON-DESTRUCTIVE TESTING
7 – CABLING/CONNECTORS
8 – FIBER OPTICS
9 – PACKAGING & INTERCONNECT MODULES
10 – MECHANICAL SYSTEMS CONDITION MONITOR
11 – POWER SUPPLIES
12 – DIAGNOSTICS
13 – COMPUTER AIDED DESIGN/MANUFACTURING (CAD/CAM)
14 – COMPOSITE MATERIALS
15 – ROBOTICS

SPERRY

GK-1137-21

RMA IMPROVEMENT

SUBSYSTEM:	MAJOR SUBSYSTEM FUNCTION:

APPLICABLE TECHNOLOGY	DESCRIPTION OF IMPROVEMENT	PREDICTED IMPROVEMENT	
		MTBF (HOURS)	MTTR (HOURS)

SPERRY

GK 1137-22

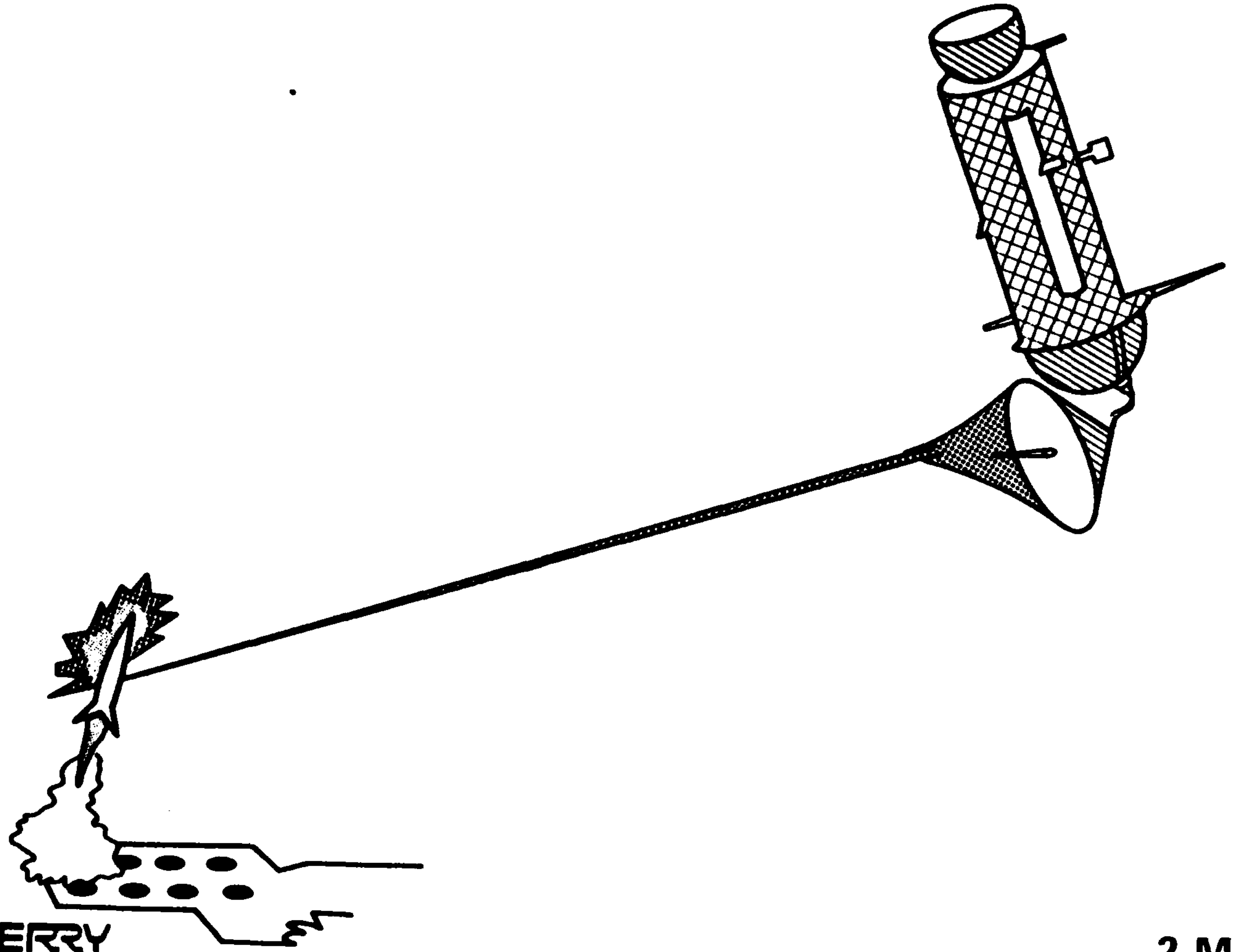
APPENDIX C

- - CASE STUDY - -

SPACE-BASED ANTI-BALLISTIC (ABM) DEFENSE

CASE STUDY

SPACE-BASED ANTI-BALLISTIC MISSILE (ABM) DEFENSE



SPERRY

2 MAY 1983

GK 19-1138

FOREWORD

THE SCENARIO, MISSION, AND LASER SYSTEM OPERATIONAL REQUIREMENTS CONTAINED HEREIN HAVE BEEN POSTULATED FOR USE IN PREPARING A MEANINGFUL RELIABILITY AND AVAILABILITY MODEL FOR USE IN THIS STUDY

SPERRY

GE 1181

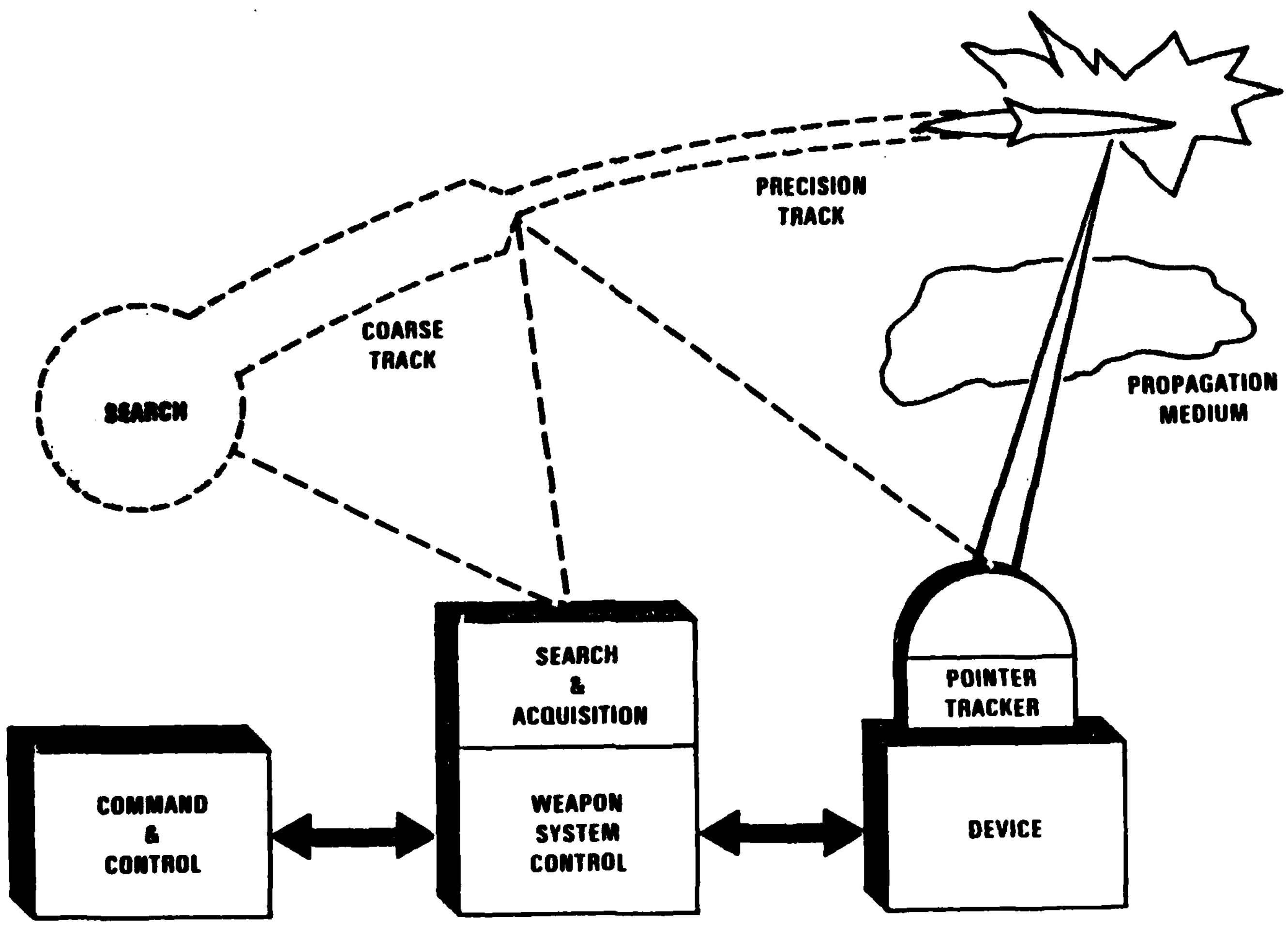
SCENARIO

- SPACE-BASED ANTI-BALLISTIC MISSILE (ABM) DEFENSE SCENARIO
  - MULTIPLE THREAT ENGAGEMENT
    - ENGAGEMENT INTERVAL: UP TO 4 MINUTES
    - NUMBER OF TARGETS: MAXIMUM OF 8

SPERRY

GK-1138 2

DIRECTED ENERGY WEAPON SYSTEM (KEY ELEMENTS)



SPERRY

GK 11.88.1

MISSION

- OUTER ZONE GLOBAL BALLISTIC MISSILE DEFENSE (GBMD) FOR THE CONTINENTAL UNITED STATES
    - ACQUIRE, TRACK, ENGAGE AND KILL ICBMs DURING THE EARLY (BOOST) PHASE OF FLIGHT
        - SPACE STATION ORBITING ALTITUDE: 500 NM
            - ENGAGE AND KILL BETWEEN 20,000 AND 120,000 FEET

SPERRY

GK 1138 4

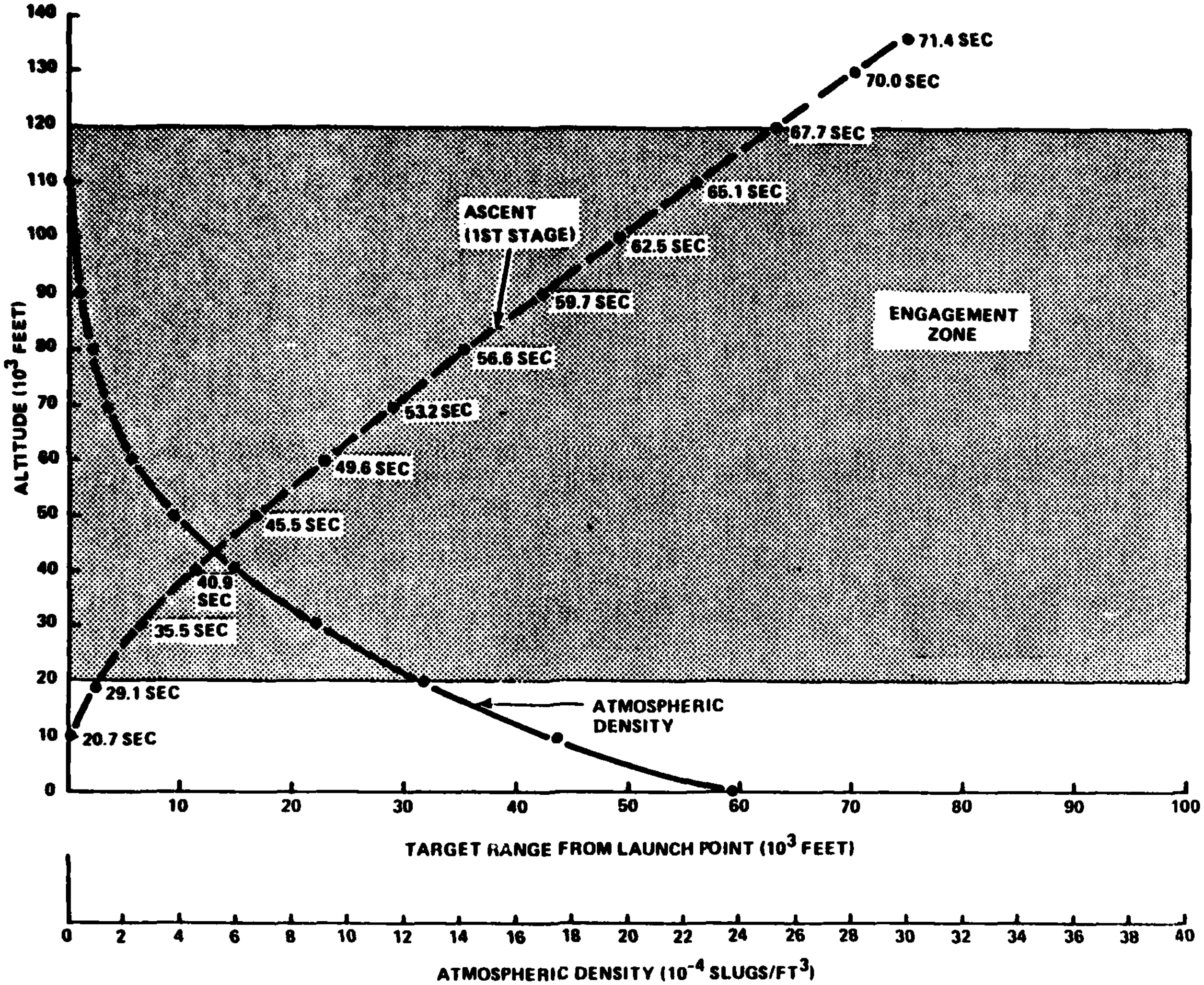
THREAT

MISSILE	THREAT TYPE	LAUNCH TRAJECTORY (DEGREES)	LAUNCH TIME (SEC)	LAUNCH RANGE (NM)	TIME TO KOR (SEC)
1	ICBM	45	0	700	60
2	ICBM	45	0	700	60
3	ICBM	45	15	675	75
4	ICBM	45	15	675	75
5	ICBM	45	30	650	90
6	ICBM	45	30	650	90
7	ICBM	45	45	625	105
8	ICBM	45	45	625	105

SPERRY

GK 1138.5

TYPICAL TARGET TRAJECTORY PROFILE



SPERRY

GK-1138-6

OPERATIONAL REQUIREMENTS

- MAXIMUM ACQUISITION RANGE: 650 NM
- MAXIMUM ACQUISITION AND TRACK INTERVAL: 5 SEC.
- MAXIMUM KILL TIME (BURN TIME): 5 SEC.
- MAXIMUM LASER RUN TIME: 50 SEC.

SPERRY

GK 1138 7

OPERATIONAL CONSTRAINTS

- METEOROLOGICAL CONDITIONS
- EMP
- COUNTERMEASURES

SPERRY

GK 1138 8

ENGAGE SEQUENCE

ENGAGEMENT TIME (SEC)	MISSILE	THREAT TYPE	TIME TO ACQUIRE (SEC)	TIME TO ENGAGE (SEC)	TIME TO KILL (SEC)	TIME TO KOR (SEC)
	1	ICBM	25	30	35	60
	2	ICBM	36	40	45	60
	3	ICBM	45	50	55	75
	4	ICBM	55	60	65	75
t_o	5	ICBM	65	70	75	90
	6	ICBM	75	80	85	90
	7	ICBM	85	90	95	105
	8	ICBM	95	100	105	105

SPERRY

GK 11.8 9

READINESS CONDITION

- SPACE-BASED SYSTEM MUST BE CAPABLE OF SUPPORTING A LASER ENGAGEMENT AT ANY TIME
  - OPERATING LIFE OF A SPACE STATION IS 5 YEARS

SPERRY

GK 1138 10

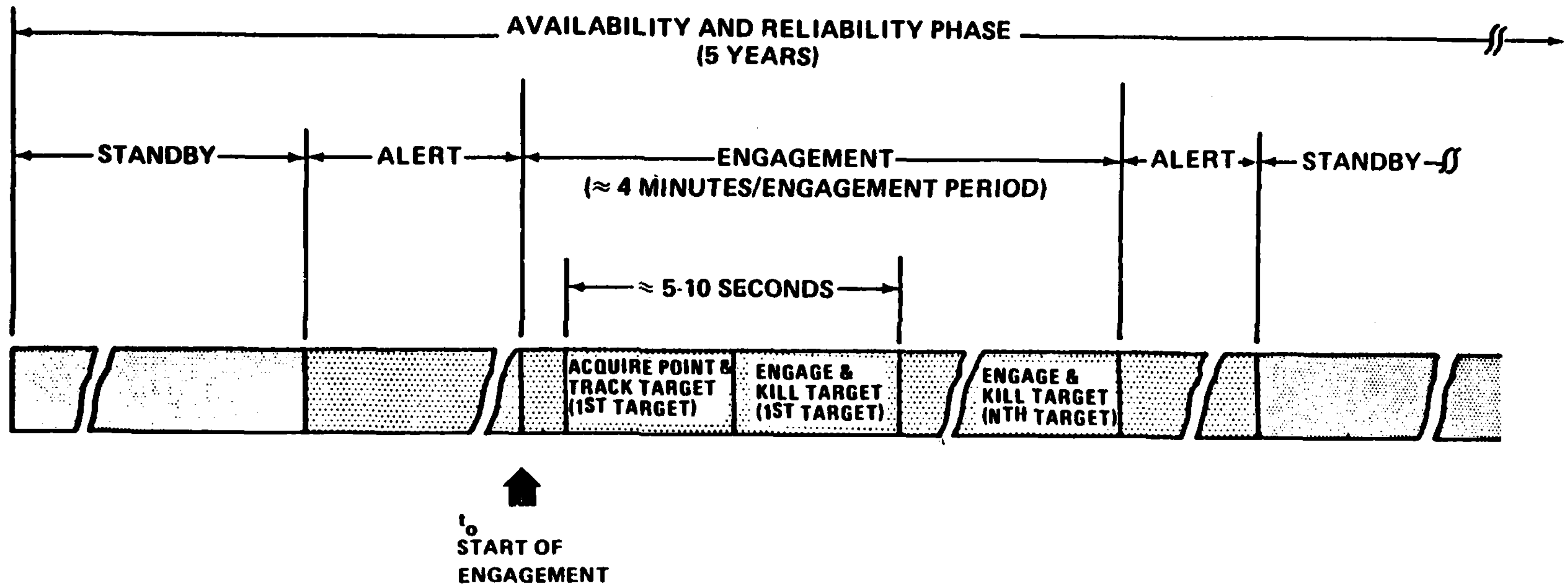
READINESS PHASES

- AVAILABILITY AND RELIABILITY PHASES ARE SYNONYMOUS
    - SYSTEM FAILURES MAY NOT BE TOLERATED

SPERRY

GK-1138 11

RA MODEL



SPERRY

GK-1138-12

GBMD SYSTEM EFFECTIVENESS

- GLOBAL BALLISTIC MISSILE DEFENSE (GBMD) SYSTEM IS CAPABLE OF SUPPORTING THREE PHASES OF ENGAGEMENT
  - EARLY (BOOST) ENGAGEMENT PHASE

    SINGLE ENGAGEMENT PROBABILITY OF SUCCESS (LASER KILL) IS 0.80
  - MID ENGAGEMENT PHASE

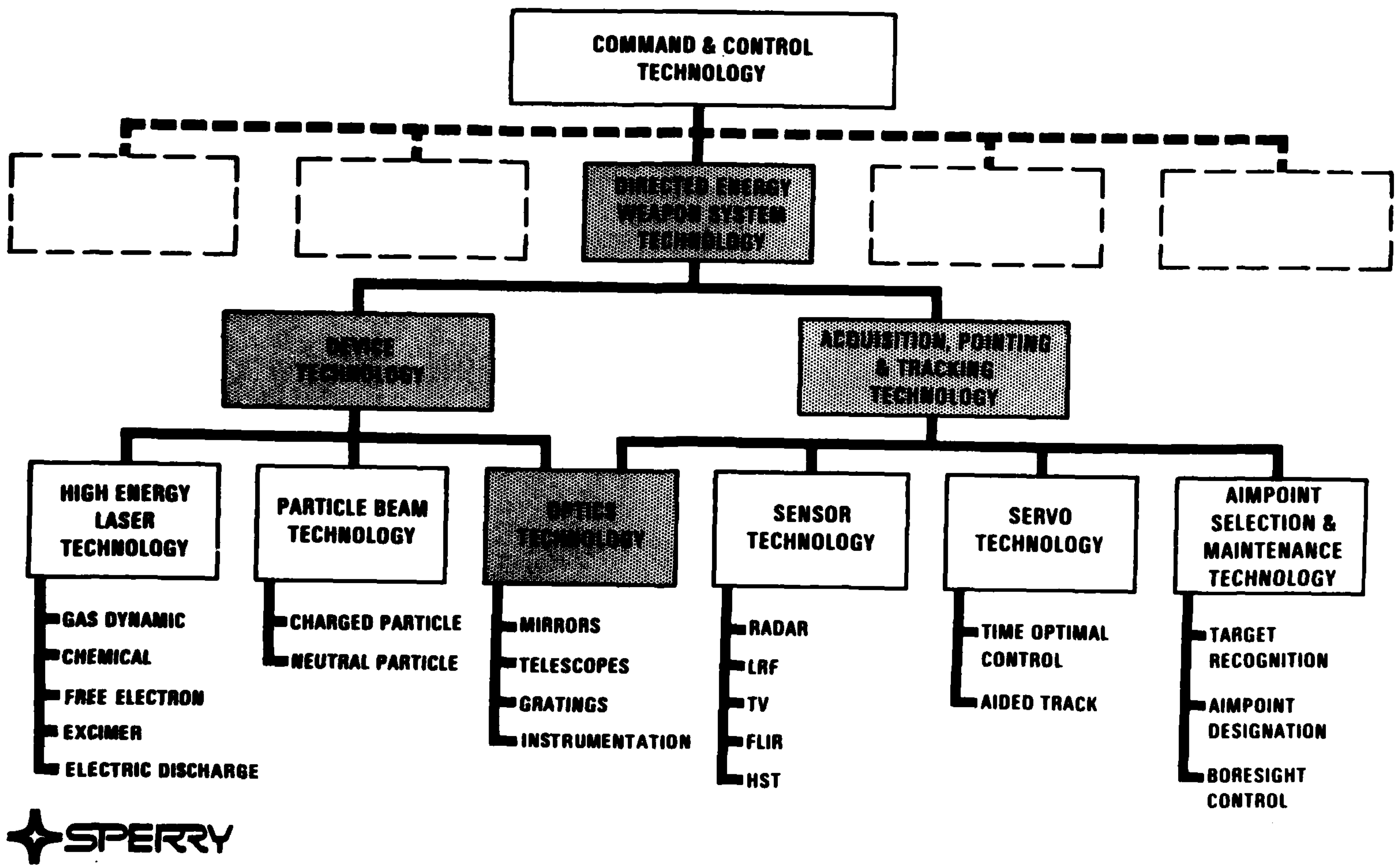
    SINGLE ENGAGEMENT PROBABILITY OF SUCCESS IS 0.80
  - TERMINAL ENGAGEMENT PHASE

    SINGLE ENGAGEMENT PROBABILITY OF SUCCESS IS 0.95

SPERRY

GK 1138 13

DIRECTED ENERGY WEAPON SYSTEMS TECHNOLOGY



GK-1138-14

SUBSYSTEM RA ALLOCATION PROCESS

SINGLE ENGAGEMENT PROBABILITY OF SUCCESS (P_S)

$$P_{(SYSTEM)} = \left[P_{(ACQ,\ P/T)}\right]_1 \left[P_{(WPN\ CONT)}\right]_2 \left[P_{(DEV)}\right]_3 \left[P_{OPT}\right]_4$$

OR

$$P_{(SYSTEM)} = \prod_{i=1}^{i=4} A_i \cdot R_i$$

WHERE: $A_i = \left[e^{-OL/MTBF_{s_i}}\right]$

$R_i = \left[e^{-T/MTBF_i}\right]$

<u>NOTE</u>: A_i = STANDBY AVAILABILITY FOR OPERATING LIFE (OL)

$MTBF_{s_i}$ = STANDBY MTBF

R_i = RELIABILITY PHASE

T = ENGAGEMENT INTERVAL

SPERRY

GK-1138 15

BASIS FOR INITIAL RA ALLOCATION

- MTBF ALLOCATIONS WERE DEFINED BASED ON ASSESSMENTS OF THE PRESENT STATE-OF-THE-ART
  - RELATIVE SUBSYSTEM COMPLEXITY
  - NATURE OF EQUIPMENT AND ENVIRONMENT
  - STANDBY MTBF IS MUCH GREATER THAN ACTIVE MTBF

SPERRY

GK-1138-16

BASIS FOR INITIAL RA ALLOCATION (CONT)

- THE RESULTANT RELATIONSHIPS THAT WERE USED TO DEVELOP THE INITIAL ALLOCATIONS ARE SHOWN BELOW

SUBSYSTEM	RELATIVE STANDBY MTBF	RELATIVE ACTIVE MTBF
ACQUISITION, POINTING, AND TRACKING	1,000	1
WEAPON CONTROL	4,000	40
DEVICE	2,000	2
OPTICS	10,000	10

SPERRY

GK 1138 17

SYSTEM RA ALLOCATION SUMMARY

SINGLE ENGAGEMENT PROBABILITY OF SUCCESS (P)				RA ALLOCATION STANDBY MTBF (HOURS)	RA ALLOCATION ACTIVE MTBF (HOURS)
SYSTEM	0.80	WEAPON CONTROL	0.9966	12,800,000	12,800
		DEVICE	0.9337	640,000	640
		OPTICS	0.9863	3,200,000	3,200
		ACQUISITION, POINTING & TRACKING	0.8718	320,000	320

SPERRY

GK 1138 18

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: WEAPON CONTROL

MTBFs: 12,800,000 HOURS

MTBF: 12,800 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	DESCRIPTION	RA ALLOCATION	
		MTBFs	MTBF
RESOURCE MANAGEMENT	• SYSTEM CONFIGURATION • READINESS VERIFICATION • CONSUMABLES INVENTORY		
SYSTEM SEQUENCING	• COMMUNICATIONS • THREAT ASSESSMENT • ENCASEMENT SEQUENCE • SYSTEM CONTROL • KILL ASSESSMENT		
SAFETY & SURVEILLANCE	• HEALTH MONITORING • CONTINGENCY ASSESSMENT • SYSTEM ABORT & SHUTDOWN		

SPERRY

GK-1138-19A

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: DEVICE

MTBFs: 640,000 HOURS

MTBF: 640 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	RA ALLOCATION	
	MTBFs	MTBF
POWER SUPPLIES		
FLUID SUPPLIES		
GAIN MEDIUM GENERATION		
EXHAUST MANAGEMENT		
INSTRUMENTATION, CONTROLS & DISPLAYS		

SPERRY

GK-1138-19B

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: OPTICS

MTBFs: 3,200,000 HOURS

MTBF: 3,200 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	DESCRIPTION	RA ALLOCATION	
		MTBFs	MTBF
BEAM GENERATION	• FEEDBACK • MAGNIFICATION • SCRAPING • MEDIA INTERFACE		
BEAM MANAGEMENT & CONTROL	• SUBSYSTEM CONTROL • HEALTH MONITORING • SHAPING • WAVEFRONT MANAGEMENT • STEERING • SIZING • STATIC, AUXILIARY BEAM & MAIN BEAM ALIGNMENT		
BEAM DELIVERY	• TURNING • SAMPLING • MEDIA INTERFACE • ENERGY SENSING		

SPERRY

GK-1138-19C

SUBSYSTEM RMA ALLOCATION

SUBSYSTEM: ACQ. P & T

MTBFs: 320,000 HOURS

MTBF: 320 HOURS

MAJOR SUBSYSTEM FUNCTIONAL GROUP	DESCRIPTION	RA ALLOCATION	
		MTBFs	MTBF
CONTROL & BORESIGHT SELECTION	• SUBSYSTEM CONTROL • HEALTH MONITORING • TARGET TRACKING • TARGET RECOGNITION		
BORESIGHT ESTABLISHMENT	• STATIC ALIGNMENT • AIMPOINT DESIGNATION		
BORESIGHT MAINTENANCE	• AIMPOINT MAINTENANCE • AUXILIARY BEAM ALIGNMENT		
BORESIGHT CORRECTION	• MAIN BEAM ALIGNMENT • BIAS COMPENSATION		

SPERRY

GK-1138-19D

SUBSYSTEM RA ASSESSMENT

SUBSYSTEM:

MTBFs: HOURS

MTBF: HOURS

MAJOR SUBSYSTEM FUNCTION	MTBFs		MTBF	
	ALLOCATED	EXISTING	ALLOCATED	EXISTING

SPERRY

GK-1138-20

TECHNOLOGY MATRIX (PRELIM)

DIRECTED ENERGY WEAPON SYSTEM	NEW SUPPORT TECHNOLOGIES														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
WEAPON CONTROL	X	X	X	X			X	X	X						
DEVICE		X	X	X		X	X	X	X	X	X	X	X	X	
OPTICS		X		X		X	X		X	X		X		X	
ACQUISITION, POINTING, & TRACKING	X	X	X	X		X	X	X	X	X	X	X	X	X	

1 – VERY HIGH SPEED INTEGRATED CIRCUITS (VHSIC)
2 – TESTING TECHNOLOGY
3 – OPERATIONAL SOFTWARE
4 – MANPOWER AND TRAINING
5 – ARTIFICIAL INTELLIGENCE
6 – NON-DESTRUCTIVE TESTING
7 – CABLING/CONNECTORS
8 – FIBER OPTICS
9 – PACKAGING & INTERCONNECT MODULES
10 – MECHANICAL SYSTEMS CONDITION MONITOR
11 – POWER SUPPLIES
12 – DIAGNOSTICS
13 – COMPUTER AIDED DESIGN/ MANUFACTURING (CAD/CAM)
14 – COMPOSITE MATERIALS
15 – ROBOTICS

SPERRY

GK 1138 21

RA IMPROVEMENT

SUBSYSTEM:	MAJOR SUBSYSTEM FUNCTION:

APPLICABLE TECHNOLOGY	DESCRIPTION OF IMPROVEMENT	PREDICTED IMPROVEMENT	
		MTBFs (HOURS)	MTBF (HOURS)

SPERRY

GK-1138-22

END

FILMED

3-84

DTIC